The Navigator Method

This method uses the directions of north [N], south [S], east [E], and west [W] on a grid to identify vector directions. North is the starting reference point of 0°. In this method, directions are stated *clockwise* from north. Figure B1.16 shows the grid to use for the navigator method.

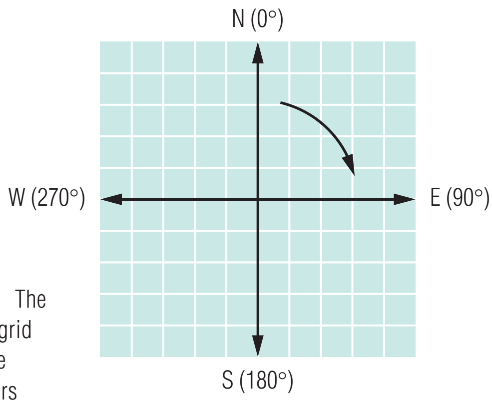


FIGURE B1.16 The navigator method grid for determining the directions of vectors

Directions given along the axis lines have positive or negative values.

- [N] and [E] are positive.
- [S] and [W] are negative.
- Directions between the axis lines are given only in degrees and are not given a positive or negative value.

Example Problem B1.5

Use the navigator method to determine the directions of the vectors A, B, C, and D shown in Figure B1.17. Give the magnitude and direction for each vector.

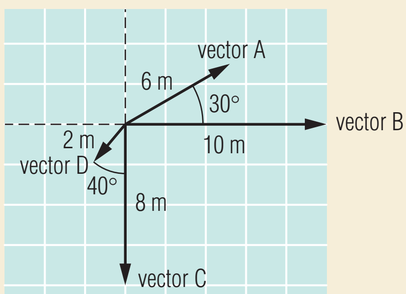


FIGURE B1.17 Vectors A, B, C, and D for Example Problem B1.5

The magnitude and directions of the vectors in Figure B1.17 are:
vector A = 6 m [60°]
vector B = 10 m [E]
vector C = –8 m [S]
vector D = 2 m [220°]

Practice Problem

7. A ball is rolling at a velocity of 2 m/s [135°]. Using a grid, sketch this vector using the navigator method.

In the two example problems B1.4 and B1.5, you probably noticed that you were identifying the same vectors. The magnitudes of the vectors were the same in both problems. The notation of their directions was different because two different methods were used to determine them. Remember to read vector problems carefully to see which method you are supposed to use to solve them.

Speed and Velocity

Now that you know the difference between scalar and vector quantities, let's look more closely at speed and velocity. In section B1.1, you used distance travelled in calculating average speed. Both distance travelled and speed are scalar quantities. Only the magnitude of each one is stated. For example, the average speed of a car may be stated as 100 km/h. To calculate average velocity, you use displacement. Both displacement and velocity are vector quantities, so you must state both the magnitude and the direction for them. For example, the average velocity of a car on the highway from Edmonton to Red Deer might be 100 km/h [S].

Using Formulas to Analyze Average Velocity

Average velocity is uniform motion that involves changing a position in a specified time. To determine the average velocity quantitatively, use the following equation:

$$\text{average velocity} = \frac{\text{displacement}}{\text{time elapsed}}$$

$$\vec{v} = \frac{\Delta \vec{d}}{\Delta t}$$

$$= \frac{\vec{d}_{\text{final}} - \vec{d}_{\text{initial}}}{t_{\text{final}} - t_{\text{initial}}}$$

Velocity is a vector quantity, so you must state its magnitude and direction.

Example Problem B1.6

A person walks 10.0 m [E] away from a bus stop in 5.00 s. What is the average velocity of the person?

Average velocity:

$$\vec{v} = \frac{\Delta \vec{d}}{\Delta t}$$

$$= \frac{10.0 \text{ m [E]} - 0.0 \text{ m}}{5.00 \text{ s} - 0.00 \text{ s}}$$

$$= \frac{10.0 \text{ m [E]}}{5.00 \text{ s}}$$

$$= 2.00 \ \frac{\text{m}}{\text{s}} \text{ [E]}$$

The person walked at an average velocity of 2.00 m/s [E].

Practice Problems

8. A student walks 10.0 m [E] in 7.00 s. Then he walks another 12.0 m [E] in 8.00 s. Determine:
   a) the displacement of the student in 15.00 s
   b) the average velocity of the student

9. A boat travels at a velocity of 8.00 m/s [N] for 14.0 s. What is the displacement of the boat?

10. An airplane flying at a velocity of 900 km/h [W] travels 400 km west. How long will the plane be in flight?

TABLE B1.7 Position of Boat Travelling past Marker Buoys

Marker	Time t (s)	Position of the Boat $\vec{d}$ (m) [E]
1	0.0	0.0
2	2.0	10.0
3	4.0	20.0
4	6.0	30.0
5	8.0	40.0
6	10.0	50.0

Using Graphs to Analyze Average Velocity

In section B1.1, you learned that graphs are an important tool for studying uniform motion. They show the relationship between two variables and provide a visual representation of the motion. You saw how distance–time graphs and speed–time graphs are visual representations of the speed of an object. You also learned how to use graphs to calculate the speed and distances travelled by objects. To analyze average velocity, you can use two types of graphs: a position–time graph and a velocity–time graph.

Plotting a Position–Time Graph

In section B1.1, you considered the speed and distance travelled by a motorboat. Now consider its velocity. Suppose a motorboat is travelling east past six marker buoys in the water placed 10.0 m apart. A person on the shore is recording the time it takes for the motorboat to pass each marker. Table B1.7 shows those measurements.

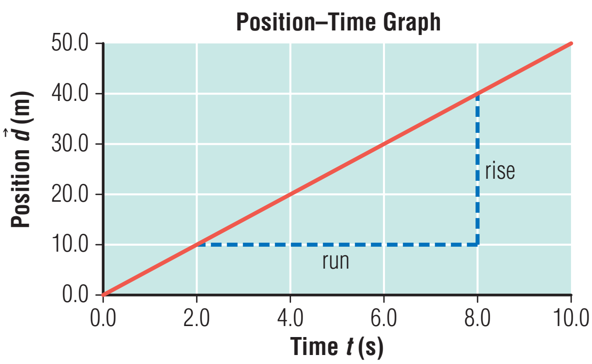


FIGURE B1.18 A position–time graph produced from the data in Table B1.7

The graph in Figure B1.18 uses the data from Table B1.7 to describe the motion of the motorboat visually. The line of best fit indicates a linear or a straight-line relationship between the position and the time taken to travel. This means that as time increases, the position also increases. The straight line of the graph shows that the motorboat's displacement in relation to the time intervals is constant. Therefore, the motorboat is moving with uniform motion. Its velocity remains constant.

You can use the slope of the line in Figure B1.18 to determine the average velocity of the motorboat.

Calculate the average velocity of the motorboat from Figure B1.18.

Average velocity:

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{\text{change in position}}{\text{change in time}}$$

$$= \text{velocity} \qquad \text{Since } \vec{v} = \frac{\Delta\vec{d}}{\Delta t}$$

$$= \frac{\Delta\vec{d}}{\Delta t}$$

$$= \frac{\vec{d}_f - \vec{d}_i}{t_f - t_i}$$

$$= \frac{40.0 \text{ m [E]} - 10.0 \text{ m [E]}}{8.0 \text{ s} - 2.0 \text{ s}}$$

$$= 5.0 \frac{\text{m}}{\text{s}} \text{[E]}$$

The average velocity of the motorboat is 5.0 m/s [E].

Example Problem B1.7

Table B1.8 contains data collected for an object travelling at uniform velocity.

a) Draw a position–time graph for the data in the table.

b) Using the graph, identify the motion occurring between $t = 0.0$ s and $t = 5.0$ s, and justify your answer.

c) From the graph, determine the average velocity between $t = 0.0$ s and $t = 5.0$ s.

TABLE B1.8 Data for Example Problem B1.7

Time t (s)	Position of Object $\vec{d}$ (m) [N]
0.0	0.0
1.0	9.9
2.0	20.1
3.0	29.8
4.0	40.2
5.0	50.0

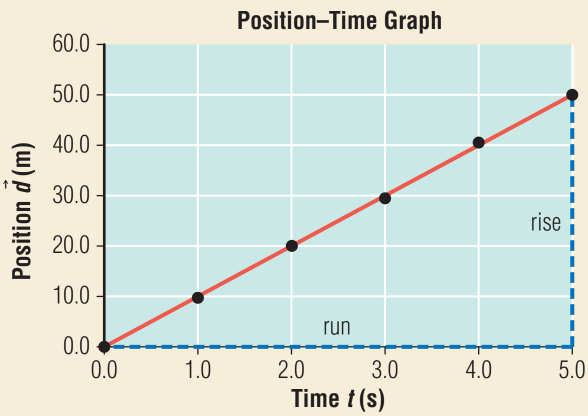


FIGURE B1.19 A position–time graph for the data from Table B1.8.

a) Figure B1.19 shows the graph drawn from the data in Table B1.8.

b) The graph is a straight line so it is showing uniform velocity between $t = 0.0$ s and $t = 5.0$ s.

c) average velocity = slope

$$\text{slope} = \frac{\text{rise}}{\text{run}}$$

$$= \frac{\vec{d}_f - \vec{d}_i}{t_f - t_i}$$

$$= \frac{50.0 \text{ m [N]} - 0.0 \text{ m [N]}}{5.0 \text{ s} - 0.0 \text{ s}}$$

$$= \frac{50.0 \text{ m [N]}}{5.0 \text{ s}}$$

$$= 10 \, \frac{\text{m}}{\text{s}} \text{ [N]}$$

Since slope = velocity, the average velocity of the object was 10 m/s [N].

Practice Problem

11. Table B1.9 contains data collected for an object travelling at uniform velocity.
    a) Draw a position–time graph for the data in the table.
    b) From the graph, determine the average velocity between $t = 0.0$ s and $t = 10.0$ s.

TABLE B1.9 Data for Practice Problem 11

Time t (s)	Position of Object $\vec{d}$ (m) [E]
0.0	0.0
2.0	49.8
4.0	100.0
6.0	150.1
8.0	199.9
10.0	250.2

Plotting a Velocity–Time Graph

A velocity–time graph is similar to the speed–time graph you studied in section B1.1. In the motorboat example, people studying the motorboat's motion would keep track of both the speed and direction to determine the velocity.

Suppose the motorboat is travelling east at uniform velocity past six marker buoys 10.0 m apart. On shore, one person is measuring the time using a stopwatch, and another is measuring the speed with a radar gun and using a compass to determine direction. Table B1.10 shows the measurements they took.

TABLE B1.10 Velocity of Boat Travelling past Marker Buoys

Marker	Time t (s)	Velocity of the Boat $\vec{v}$ (m/s) [E]
1	0.0	5.0
2	2.0	5.0
3	4.0	5.0
4	6.0	5.0
5	8.0	5.0
6	10.0	5.0

Figure B1.20 is the graph of the data from Table B1.10. The line of best fit is a straight line. This indicates a linear relationship between the velocity of the boat and the time it took to travel past the markers. The line is also horizontal. This means that the velocity remained constant during the time the motorboat was moving past the markers. The boat is travelling with uniform motion. In section B1.3, you will learn about motion that is not uniform, when objects increase and decrease velocity.

*re*SEARCH

The most common way to measure the magnitude of the velocity of vehicles is km/h. However, pilots and sea captains measure velocity in knots. Use the Internet or your local library to research the term "knot" as used to describe the velocity of an object. How did this term originate? What is a nautical mile? How do km/h and knots compare? Write a brief summary of your findings. Begin your search at www.pearsoned.ca/school/science10

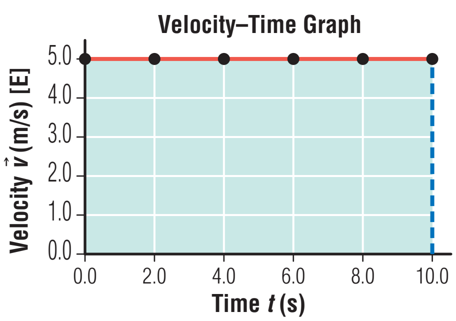


FIGURE B1.20 A graph of the velocity of the motorboat as a function of time

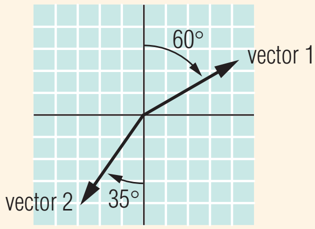
B1.2 Check and Reflect

Knowledge

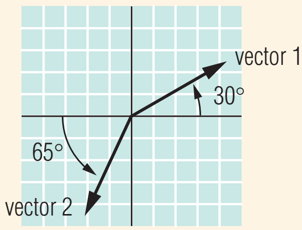
1. What is one difference between a scalar and a vector quantity?

2. Give two examples of scalar quantities and two examples of vector quantities.

3. Use the navigator method to determine the directions of vector 1 and vector 2 shown below.



4. Use the *x*-axis method to determine the directions of vector 1 and vector 2 shown below.



Applications

5. A ball rolls 10.0 m [S] in a time of 6.00 s, hits a wall, and rolls back a distance of 15.0 m [N] in a time of 10.00 s. Determine:

a) the distance travelled by the ball

b) the displacement of the ball

c) the average speed of the ball

d) the average velocity of the ball

6. An air puck is propelled from one side of an air table. It hits an elastic on the other side, and the elastic propels it back to the side where it started. Students recorded the motion of the air puck and analyzed the data. Their data are shown in the table at the top of the right column.

a) Draw a position–time graph of the data in the table.

b) Calculate the slope of the graph. What can you determine from the value of the slope?

Time t (s)	Position of the Air Puck $\vec{d}$ (cm)
0.00	0.00
0.10	5.25 [E]
0.20	10.51 [E]
0.30	15.74 [E]
0.40	10.52 [E]
0.50	5.26 [E]
0.60	0.00

7. Use the data table in question 6 to complete the following table in your notebook. Draw a velocity–time graph using the completed table. Then answer the questions below.

a) How does the graph show that motion is uniform?

b) How does the graph distinguish between uniform motion in one direction and uniform motion in the opposite direction?

Time Interval Δt (s)	Velocity of the Air Puck $\vec{v}$ (cm/s) (hint: Use $\vec{v} = \frac{\Delta \vec{d}}{\Delta t}$)
0.00 – 0.10	____ [E]
0.10 – 0.20	____ [E]
0.20 – 0.30	____ [E]
0.30 – 0.40	____ [W]
0.40 – 0.50	____ [W]
0.50 – 0.60	____ [W]

Extension

8. Draw a position–time graph and a velocity–time graph of each of the motions described below:

a) A car travelling at a uniform velocity of 100 km/h, moves 200 km [S] in 2.0 h. It rests for 1.0 h and then returns 100 km [N] in 1.0 h.

b) A hummingbird flying at a uniform velocity of 10 m/s travels 40 m [E] in 4.0 s. It stops at a feeder for 5.0 s, and then flies 20 m west for 2.0 s.

infoBIT

A jumbo jet can change its speed during take-off from rest to 200 km/h (55.6 m/s) in about 12 seconds. A NASA shuttle craft moves from rest to 180 km/h (50 m/s) in the first 4 s of lift-off and then increases its speed to 28 000 km/h (7800 m/s) in the next 8.5 minutes.

B1.3 Acceleration

On a long-distance flight, your plane may fly for long periods at 900 km/h. Unless you have a window seat, however, it may seem like the plane is not moving at all. Uniform motion can be relaxing—even at such a high speed. The excitement comes at the beginning of the trip as the plane takes off (Figure B1.21). Its speed changes rapidly from rest to take-off speed in several seconds. Because the airplane's speed is increasing, so is its velocity. This change in velocity during a specific time interval is called **acceleration**. You can experience acceleration in a vehicle or on your own. For example, when you start to run for the bus or dive into a swimming pool, you are accelerating.

FIGURE B1.21 An airplane accelerates rapidly when it takes off. Once it reaches cruising altitude, it travels in uniform motion for long periods.

Types of Acceleration

Uniform motion is the simplest type of motion, but accelerated motion is the most common type of motion. Like velocity, acceleration is a vector quantity, so you must determine both its magnitude and direction. Different types of acceleration are possible because both the magnitude and direction of velocity can change. When an object is speeding up, the magnitude of its velocity is increasing. When an object is slowing down, the magnitude of the velocity is decreasing.

Positive acceleration occurs in two ways:

1) when the change in both the magnitude of the velocity and the direction are positive (Figure B1.22(a)).
2) when the change in both the magnitude of the velocity and the direction are negative (Figure B1.22(b)).

Negative acceleration also occurs in two ways:

1) when the change in the magnitude of the velocity is negative while the direction is positive (Figure B1.22(c)).
2) when the change in the magnitude of the velocity is positive and the direction is negative (Figure B1.22(d)).

FIGURE B1.22 Examples of positive and negative acceleration

(a) Positive acceleration: both the change in the magnitude and the direction of the velocity are positive.

(b) Positive acceleration: both the change in the magnitude and the direction of the velocity are negative.

(c) Negative acceleration: the change in the magnitude of the velocity is negative while the direction is positive.

(d) Negative acceleration: the change in the magnitude of the velocity is positive but the direction is negative.

Your study of accelerated motion will concentrate on changes in magnitude of velocity in one direction. You will consider both accelerated motion that is speeding up and accelerated motion that is slowing down.

Using Formulas and Graphs to Analyze Accelerated Motion

As with uniform motion, you can study accelerated motion quantitatively by using formulas and graphs. To calculate acceleration, use the following formula:

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time interval}}$$

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$$

where $\Delta \vec{v} = \vec{v}_{\text{final}} - \vec{v}_{\text{initial}}$

and $\vec{v}_{\text{f}}$ is the final velocity and $\vec{v}_{\text{i}}$ is the starting velocity

so, $$\vec{a} = \frac{\vec{v}_{\text{f}} - \vec{v}_{\text{i}}}{\Delta t}$$

Remember that acceleration is a vector quantity so you must determine the magnitude and the direction of the acceleration.

Example Problem B1.8

A racing car accelerates from rest to a speed of 200 km/h (55.6 m/s) [E] in 6.00 s. What is the acceleration of the car?

$$\vec{a} = \frac{\vec{v}_{\text{f}} - \vec{v}_{\text{i}}}{\Delta t}$$

$$= \frac{55.6\ \frac{\text{m}}{\text{s}}\ [\text{E}] - 0.00\ \frac{\text{m}}{\text{s}}}{6.00\ \text{s}}$$

$$= 9.27\ \frac{\frac{\text{m}}{\text{s}}}{\text{s}}\ [\text{E}] \text{ or } 9.27\ \frac{\text{m}}{\text{s}^2}\ [\text{E}]$$

The car's velocity is increasing at the rate of 9.27 m/s^2 [E]. (This is positive acceleration.)

Note that the units for velocity were converted from km/h to m/s, and the units for acceleration are stated as m/s^2.

In some situations, only the magnitude of the acceleration is required, and the direction is ignored. For these situations, the formula can be adjusted so that the vectors are not included:

$$a = \frac{v_{\text{f}} - v_{\text{i}}}{\Delta t}$$

Practice Problems

12. A shuttle craft accelerates from rest to a velocity of 50 m/s [upward] in 4.00 s. What is its acceleration?

13. A baseball thrown at 25.0 m/s strikes a catcher's mitt and slows down to rest in 0.500 s. What is the magnitude of the ball's acceleration?

14. A hockey puck travelling at 10.0 m/s strikes the boards, coming to rest in 0.0300 s. What is the magnitude of the puck's acceleration?

15. A car driver applies the brakes and slows down from 15.0 m/s [E] to 5.00 m/s [E] in 4.00 s. Determine the car's acceleration.

Plotting a Position–Time Graph

In section B1.2, you learned that you could determine the velocity of an object from the slope of a position–time graph. The line of best fit for an object travelling with uniform motion was shown to be a straight line because the velocity was uniform. For accelerated motion, the line of best fit is a smooth curve. Here's an example.

Suppose that a motorboat is travelling with accelerated motion in an easterly direction. It passes marker buoys placed 5 m apart. As the boat passes the first marker buoy, a person on shore starts to estimate and record the position of the motorboat every 2 s relative to the first marker buoy. Table B1.11 shows the data collected by the person on shore.

TABLE B1.11 Change in the Position of the Motorboat

Time t (s)	Position of the Boat $\vec{d}$ (m) [E]
0	0
2	1
4	4
6	9
8	16
10	25

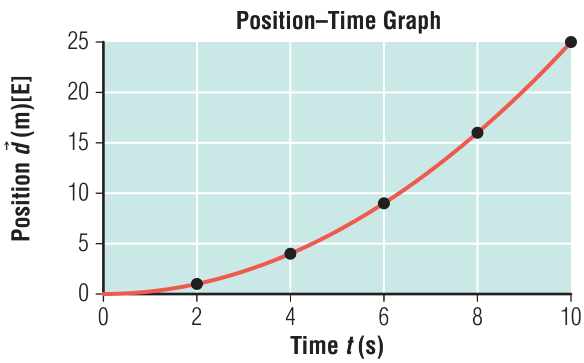


FIGURE B1.23 Graph of the position of the motorboat as a function of time

The graph in Figure B1.23 describes the accelerated motion of the motorboat. The slope of the line is gradually increasing, which indicates that the velocity of the boat is gradually increasing or accelerating. The shape of the curve of a graph of accelerated motion indicates whether the object has a positive or a negative acceleration.

Figure B1.24 shows two position–time graphs of accelerated motion. Graph (a) has an increasing slope, which indicates positive acceleration. Graph (b) has a decreasing slope, which indicates negative acceleration.

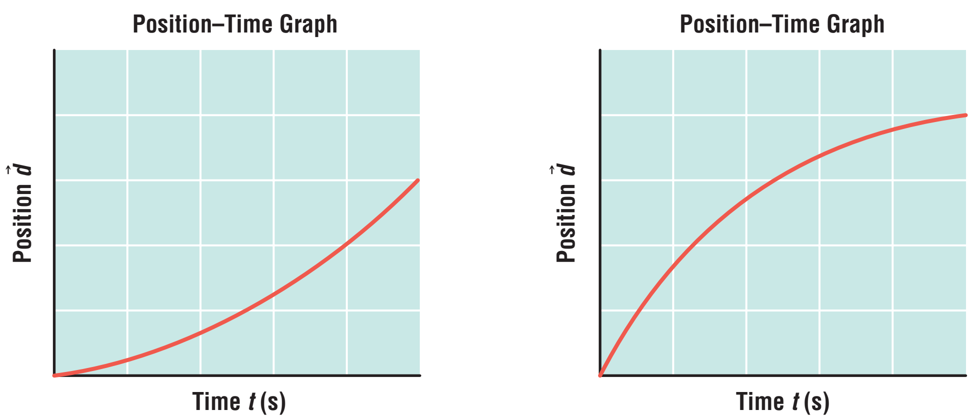


FIGURE B1.24 (a) This graph represents positive acceleration because the slope is increasing.

(b) This graph represents negative acceleration because the slope is decreasing.

Example Problem B1.9

Table B1.12 shows data for an object travelling with accelerated motion.

a) Draw a position–time graph for the data shown in the table.

b) Using the graph, identify the motion occurring in the time intervals given below. Justify your answer for each one.

i) between $t = 0.0$ s and $t = 3.0$ s

ii) between $t = 3.0$ s and $t = 6.0$ s

iii) between $t = 6.0$ s and $t = 8.0$ s

TABLE B1.12 Time and Position Data for Example Problem B1.9

Time t (s)	Position $\vec{d}$ (m) [E]
0.0	0.0
1.0	10.0
2.0	40.0
3.0	90.0
4.0	140.0
5.0	190.0
6.0	240.0
7.0	270.0
8.0	290.0

a) Figure B1.25 shows the graph drawn from the data in Table B1.12.

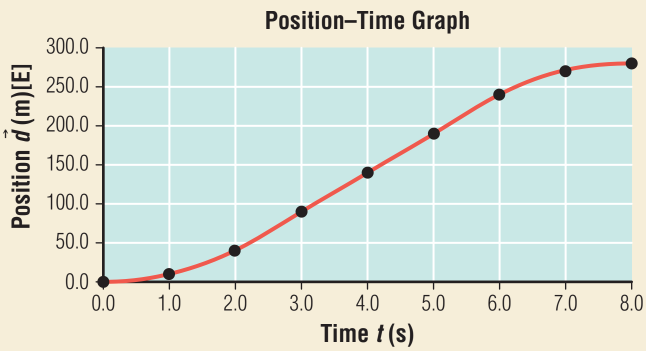


FIGURE B1.25 Graph of the data in Table B1.12

b) i) The curve has an increasing slope so it shows positive acceleration [E].

ii) The straight line shows uniform motion [E].

iii) The curve has a decreasing slope so it shows negative acceleration [E].

Practice Problem

16. Table B1.13 shows data for a rollercoaster travelling with accelerated motion.

a) Draw a position–time graph for the data shown in the table.

b) Using the graph, identify the motion occurring in the time intervals given below. Justify your answer for each one.

i) between $t = 0.0$ s and $t = 3.0$ s

ii) between $t = 3.0$ s and $t = 6.0$ s

iii) between $t = 6.0$ s and $t = 8.0$ s

TABLE B1.13 Time and Position Data for Practice Problem 16

Time t (s)	Position $\vec{d}$ (m) [E]
0.0	0.0
1.0	2.0
2.0	8.0
3.0	18.0
4.0	28.0
5.0	38.0
6.0	48.0
7.0	54.0
8.0	56.0

Activity B3

Inquiry Lab

Student Reference 5, 6, 7, 11

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Get in Motion!

Before You Start...

Accurately describing the motion of an object is sometimes difficult. You must know where the object is relative to a point of reference. You need to have an idea of what direction the object is moving in and how fast it is going. You must also be aware of any changes in speed (acceleration). One excellent way to describe the motion of an object is with the help of a motion sensor.

Motion sensors use pulses of sound that reflect off an object to determine its position. In this activity, you will use a motion sensor connected to a computer to track the motion of an object. By producing a graph of the motion, you will be able to describe when the object is moving, and whether it is moving at a constant speed or is changing speed. In this activity, you will be the moving object!

The Question

What does the movement of an object look like on a position–time graph?

The Hypothesis

Look at step 2 of the procedure and form a hypothesis for this investigation based on the question above.

Variables

Identify the type of data you will collect to support your hypothesis. State the manipulated, responding, and controlled variables in this investigation.

Materials and Equipment

computer and data-collection software
motion sensor
printer

alternative materials if no motion sensor is available

metre-sticks
adding machine tape
marker
tape
stopwatch
grid paper

Procedure

Method 1: Using a Motion Sensor

1. Connect the motion sensor (Figure B1.26) to the computer and activate the data-collection software. Configure the software to display a position–time graph.
2. Have a partner activate the motion sensor. Stand in front of the sensor, as shown in Figure B1.27. Perform the following sequence.
   - Stand still for 5 s.
   - Move slowly away from the sensor at a steady rate.
   - When you are about 2–3 m away from the sensor, gradually come to a stop.
   - Stand still for a few seconds.

FIGURE B1.26 A motion sensor

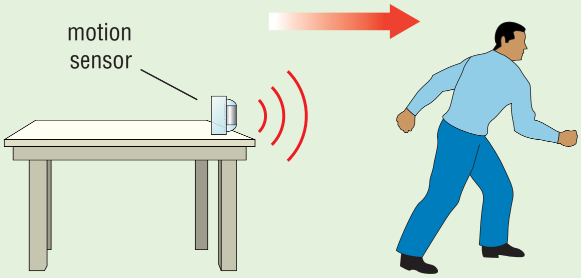


FIGURE B1.27 Step 2

3. When you have completed the sequence, your partner should stop recording.
4. Once you have your graph scaled correctly on screen, print it out.
5. Repeat the sequence in step 2, but move more quickly.

Method 2: Using Metre-Sticks and Paper

6. Lay out the metre-sticks end-to-end and tape down a long strip of paper (adding machine tape) next to the sticks.
7. Stand at the beginning of the path, and start the stopwatch. Begin the motions described in step 2, but while you are moving, call out "Now!" every second. (If you find this difficult, have someone else control the stopwatch.)
8. Have a partner follow you and mark your position on the paper or at each time interval indicated by "Now."
9. Repeat steps 7 and 8 as many times as necessary to obtain a good result. (It may take practice!)
10. Measure the positions of consecutive marks on the paper, and record the position–time data in a table. Use the data to construct a position–time graph.
11. Repeat the procedure, but do the movements more quickly.

Analyzing and Interpreting

1. Label the following on the position–time graph you have printed or created:
   - areas of no movement
   - areas of constant speed
   - areas of acceleration
2. Explain why you labelled the areas as you did in step 1 of Analyzing and Interpreting. For example, what characteristic of the line on the graph indicates no motion? Constant speed? Acceleration?
3. How are different speeds indicated on your graphs? Explain.

Forming Conclusions

4. Write a few summary sentences that answer the question: "What does the movement of an object look like on a position–time graph?"
5. Did your results match your hypothesis?

Applying and Connecting

6. Imagine a car leaving the school parking lot. It slowly accelerates in a straight line away from the school, and then travels at a constant slow speed for a period of time. The car then slows down as it approaches a stop sign, and remains motionless for a period of time. The car then continues in the same straight line, accelerating rapidly to a high speed. It continues at that high speed for a period of time before coming to an abrupt halt. Sketch a position–time graph of the car's position.

Extending

7. Refer back to the motion graphs you created in this activity. For the areas of the graph that indicate constant speed, calculate the actual speed you were travelling. Speed is calculated by dividing distance by time. In the case of the graph, this can be done for the line indicating constant speed, by calculating the *slope* of the line (how much the line *rises* or *falls*, divided by how much it *runs*).

Plotting a Velocity–Time Graph

Again, suppose that the motorboat is accelerating in an easterly direction. A person on the shore uses a radar gun and records the velocity of the motorboat every 1.0 s, as soon as it passes the first marker buoy. Table B1.14 shows the measurements taken by the person on shore.

TABLE B1.14 Change in the Velocity of the Motorboat

Time t (s)	Velocity of Boat $\vec{v}$ (m/s) [E]
0.0	0.0
1.0	2.0
2.0	4.0
3.0	6.0
4.0	8.0
5.0	10.0

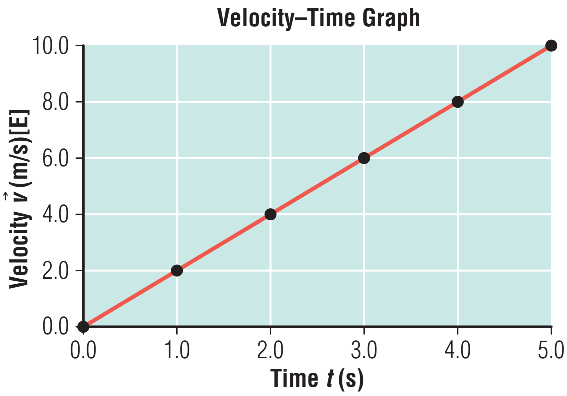


FIGURE B1.28 Graph of the velocity of the motorboat as a function of time

*re*SEARCH

Which would accelerate the fastest and win a 50-m race between a racehorse, a race car, and a human? Use the Internet or your local library to research the acceleration of a racehorse, a race car, and the fastest human. Using the data from your research, determine who would win the race. Write a brief summary of your findings. Begin your search at www.pearsoned.ca/school/science10

The graph in Figure B1.28 uses the data from Table B1.14 to describe the accelerated motion of the motorboat. The graph shows the line of best fit for this data. This is a straight line with an increasing slope. This indicates that the velocity of the motorboat is increasing with time. The slope of the line of best fit can be calculated as follows:

$$\text{slope} = \frac{\text{rise}}{\text{run}}$$

$$= \frac{\Delta\vec{v}}{\Delta t} \qquad \text{Since acceleration} = \frac{\Delta\vec{v}}{\Delta t}$$

$$= \text{acceleration}$$

$$= \frac{10.0\ \frac{\text{m}}{\text{s}}\ [\text{E}] - 0.0\ \frac{\text{m}}{\text{s}}\ [\text{E}]}{5.0\ \text{s} - 0.0\ \text{s}}$$

$$= \frac{10.0\ \frac{\text{m}}{\text{s}}\ [\text{E}]}{5.0\ \text{s}}$$

$$= 2.0\ \frac{\text{m}}{\text{s}^2}\ [\text{E}]$$

The acceleration of the boat is 2.0 m/s^2 [E]. If the slope had a negative value, this would indicate that the boat had a negative acceleration. In other words, it was slowing down.

Figure B1.29 shows two velocity–time graphs of accelerated motion. Graph (a) has an increasing slope, which indicates positive acceleration. Graph (b) has a decreasing slope, which indicates negative acceleration.

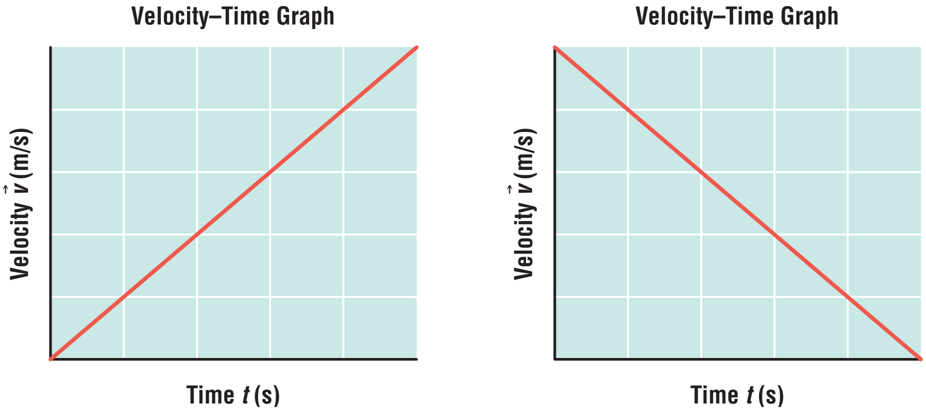


FIGURE B1.29 (a) This graph represents positive acceleration because the slope is increasing.

(b) This graph represents negative acceleration because the slope is decreasing.

Example Problem B1.10

Table B1.15 shows data for an object travelling with accelerated motion.

a) Draw a velocity–time graph for the data shown in the table.

b) Using the graph, identify the motion occurring in the time intervals given below. Justify your answer for each one.

  i) between $t = 0.0$ s and $t = 3.0$ s

  ii) between $t = 3.0$ s and $t = 5.0$ s

  iii) between $t = 5.0$ s and $t = 8.0$ s

TABLE B1.15 Time and Velocity Data for Example Problem B1.10

Time t (s)	Velocity $\vec{v}$ (m/s) [E]
0.0	0.0
1.0	2.0
2.0	4.0
3.0	6.0
4.0	6.0
5.0	6.0
6.0	4.0
7.0	2.0
8.0	0.0

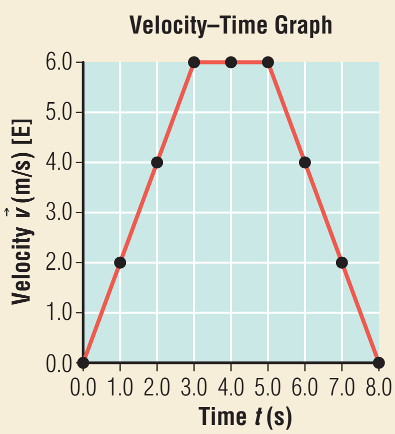


FIGURE B1.30 Graph of the data in Table B1.15

a) Figure B1.30 shows the graph drawn from the data in Table B1.15.

b) i) The straight line with a positive slope shows that the object was travelling with positive acceleration [E].

  ii) The straight horizontal line shows uniform motion [E].

  iii) The straight line with a negative slope shows negative acceleration [E].

Practice Problem

17. Table B1.16 shows data for an object travelling with accelerated motion.

a) Draw a velocity–time graph for the data shown in the table.

b) Using the graph, identify the motion occurring in the time intervals given below. Justify your answer for each one.

  i) between $t = 0.0$ s and $t = 3.0$ s

  ii) between $t = 3.0$ s and $t = 5.0$ s

  iii) between $t = 5.0$ s and $t = 8.0$ s

TABLE B1.16 Time and Velocity Data for Practice Problem 17

Time t (s)	Velocity $\vec{v}$ (m/s) [E]
0.0	0.0
1.0	5.0
2.0	10.0
3.0	15.0
4.0	15.0
5.0	15.0
6.0	10.0
7.0	5.0
8.0	0.0

B1.3 Check and Reflect

Knowledge

1. Identify the following motions as positive or negative accelerations:

a) An object changes its velocity from 10 m/s [E] to 20 m/s [E] in 4.0 s.

b) An object changes its velocity from 20 m/s [E] to 10 m/s [E] in 4.0 s.

c) An object changes its velocity from 10 m/s [W] to 20 m/s [W] in 4.0 s.

d) An object changes its velocity from 20 m/s [W] to 10 m/s [W] in 4.0 s.

2. Explain how an object can be speeding up and have a negative acceleration.

3. A train is travelling along a straight stretch of track.

a) Identify one situation when the train could be exhibiting positive acceleration.

b) Identify one situation when it could be exhibiting negative acceleration.

Applications

4. Rearrange the acceleration equation,

$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$, to solve for:

a) Δt

b) $\vec{v}_f$

5. A transit bus travelling at 15 m/s [N] applies its brakes and stops in 3.0 s. What is the acceleration of the bus?

6. A race car driver accelerates his car from 25.0 m/s [W] to 40.0 m/s [W] in 4.00 s. What is the acceleration of the car?

7. A golf ball rolling on a green slows down from 2.00 m/s to 1.50 m/s in 2.00 s. What is the magnitude of the acceleration of the ball?

8. An object starts from rest and accelerates at 1.30 m/s² [N] for 6.00 s. What is the final velocity of the object?

9. An object, initially at rest, is dropped off a building and accelerates to Earth at −9.81 m/s² [downward]. How long will it take for the object to reach a final velocity of −49.1 m/s [downward]?

10. The following table shows the data collected as a ball rolled down an inclined plane.

Time t (s)	Position of the Ball Down the Incline $\vec{d}$ (cm)	Time Interval Δt (s)	Velocity of the Ball During the Time Interval $\vec{v}$ (cm/s)
0.00	0.00	—	—
2.00	4.00	0.00 – 2.00	
4.00	16.00	2.00 – 4.00	
6.00	36.00	4.00 – 6.00	
8.00	64.00	6.00 – 8.00	
10.00	100.00	8.00 – 10.00	

a) Draw a position–time graph of the motion. Explain how the graph proves either uniform or accelerated motion.

b) Complete the above table of values in your notebook, and draw a velocity–time graph of the motion.

c) Using the velocity–time graph, calculate the acceleration of the ball.

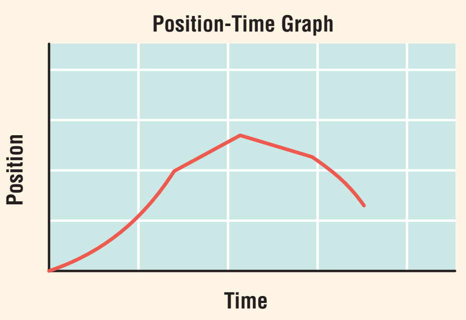
d) Explain how you would determine the displacement of the ball using the:
 i) position–time graph
 ii) velocity–time graph

Extensions

11. The position–time graph below depicts the motion of an object:

a) Describe the motion in each segment.

b) Draw a velocity–time graph to match your description in part (a).



12. You are observing an airplane taking off from a runway. Describe the measurements you could take to determine the acceleration of the airplane.

B1.4 Work and Energy

The question of why objects exhibit uniform or accelerated motion puzzled philosophers and scientists for centuries. It wasn't until the 1600s that Isaac Newton described the important relationships between forces and motion.

Activity B4

QuickLab

Forces

Purpose

To distinguish between observed forces

Materials and Equipment

Station 1:
a spring scale (20 N)
2 10-N weights
2 pulleys and clamps
string
sheet of paper
tape

Station 2:
a retort stand with a ring clamp
1 10-N weight with hooks on both ends
string

Procedure

Station 1:

1. Clamp the pulleys on opposite ends of a table. Tape the paper on the face of the scale to hide the reading.
2. Attach a 10-N weight to each end of the scale. Use enough string so that each weight hangs over a pulley with the scale centred between the two pulleys (Figure B1.31).
3. Without looking at the reading on the scale, write down what you think it will be. Remove the paper and record the reading on the scale.

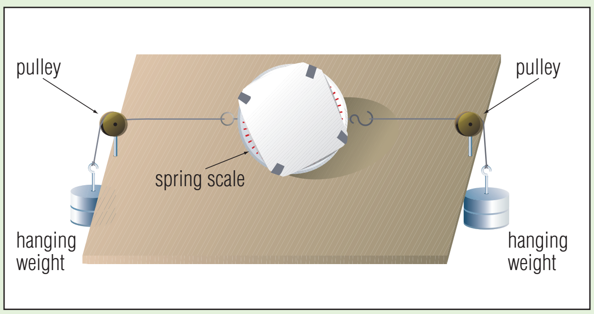


FIGURE B1.31 Pulleys and weights for procedure step 2

Station 2:

4. Tie a string to both ends of the weight. Attach one string to the ring on the retort stand, and let the other string hang down freely (Figure B1.32).
5. Predict which string will break when you pull on the lower string. Slowly and gently pull on the lower string. Gradually increase the "pull" until a string breaks.

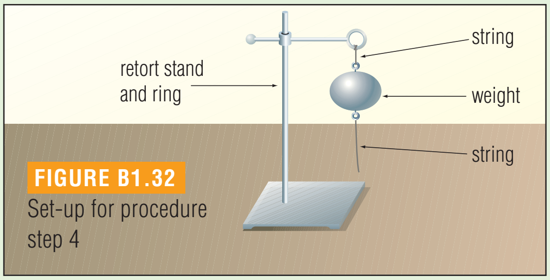


FIGURE B1.32 Set-up for procedure step 4

6. Reattach the weight to the ring on the retort stand. Predict which string will break when you give the lower string a quick jerk. Give the lower string a quick jerk.

Questions

Station 1:

1. Are there forces acting on the scale? Justify your answer.
2. Are these forces a "push" or a "pull" on the scale?
3. What is the cause of the forces?
4. What reading did you predict for the scale? What was the actual reading? Was it the same as your prediction?
5. Explain why the reading on the scale must be the same as one of the hanging weights (10 N).

Station 2:

6. Before you pulled gently on the bottom string, which string did you predict would break? Which string broke?
7. Before you jerked sharply on the bottom string, which string did you predict would break? Which string broke?
8. Explain why a different string broke in each procedure. (Hint: Consider the action of the hanging weight in each procedure.)

*info*BIT

One newton of force is roughly equivalent to the weight of a lemon in your hand.

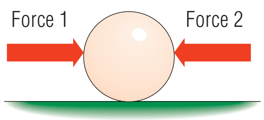
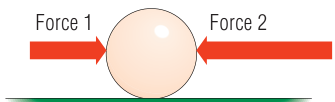


FIGURE B1.33 (a) Balanced forces are equal in magnitude (force 1 equals force 2) but opposite in direction. They cancel each other out.



(b) Unbalanced forces are forces that are not equal in magnitude (force 2 is greater than force 1) or are not opposite in direction.

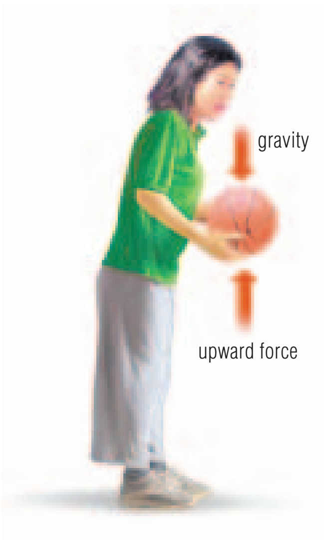


FIGURE B1.35 Lifting a ball from the floor requires the application of a force to overcome the force of gravity.

Force

A ball at rest on a billiard table will remain at rest. It does not move because all forces acting on it are balanced (Figure B1.33(a)). Recall that a **force** is defined as a push or a pull on an object. Force is measured in newtons. The resting ball will only move when an unbalanced force is applied to it through a distance. With an unbalanced force, the force acting in one direction is greater than the force acting in the opposite direction (Figure B1.33(b)). If a person hits a stationary ball with a cue, he or she used energy to apply the force. The energy was transferred from the person to the ball through the cue. The ball then gained energy and, as a result, acquired a change in motion.

Once an object is in motion, it tends to remain in motion, moving at a constant speed in a straight line. However, if an unbalanced force is applied to the moving ball, it will either speed up or slow down (accelerate). If the unbalanced force is applied in the same direction as the ball's motion, the ball will speed up (Figure B1.34(a)). The person applying the force to the ball transfers energy to the ball. If the unbalanced force, such as friction between the table and the ball, is applied in the direction opposite to the direction of the ball's motion, the ball will slow down (Figure 1.34(b)). Without such a resistive force, the ball would tend to keep moving.

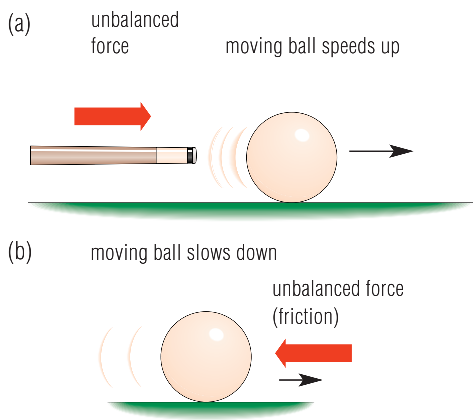


FIGURE B1.34 An unbalanced force acting on a moving ball will speed up (a) or slow down (b) the ball, depending on the direction of the force.

In the absence of any external unbalanced forces, such as resistive forces, all objects tend to maintain uniform motion or stay at rest. An object in motion will stay in motion, and no energy input is required to maintain uniform motion. The two examples above illustrate that if an unbalanced force is applied to an object, energy is transferred to the object. This causes a change in the motion of the object.

In Figure B1.35, the ball is lifted and held above the floor. For this to occur, the person had to apply a force in the opposite direction to the downward force of Earth's gravity to raise the ball. The person doing the lifting did work and the energy was transferred to the ball. This energy transfer results in a change in the ball's position relative to Earth's surface.

This situation describes how one force (supplied by the person) applied against another force (due to Earth's gravitational field) can result in a transfer of energy, resulting in a change in position of the object.

Figure B1.36 illustrates a person boring a hole with a cork borer. The person must apply a force to turn the cork borer and, in the process, the person uses up energy. This energy is transferred to the cork and the cork borer and results in a change in temperature. Both the cork and the cork borer will now feel warm to the touch.

All these examples have something in common: all involve using energy to apply a force to an object over a distance, and the object then changes in some way. They are all the result of an energy transfer, and an application of a force applied through a distance was required to achieve the change. Somehow, force and energy are related.

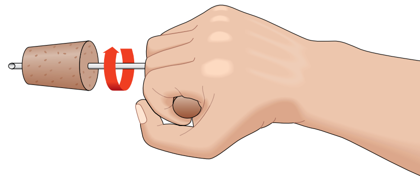


FIGURE B1.36 A person applies a force to turn the cork borer. Energy transfers to the cork borer.

Work

Whenever a force moves an object through a distance that is in the direction of the force, then **work** is done on the object. The work done is calculated by multiplying the force by the distance travelled in the direction of the force.

$$\begin{aligned} \text{work} &= \text{force} \times \text{distance the object travels} \\ W &= Fd \\ \text{joule} &= \text{newton} \times \text{metre} \qquad \text{Note: N} = \frac{\text{kg·m}}{\text{s}^2} \\ 1\ \text{J} &= 1\ \text{N·m} \\ &= \frac{1\ \text{kg·m}}{\text{s}^2}\text{·m} \\ &= 1\ \frac{\text{kg·m}^2}{\text{s}^2} \end{aligned}$$

In physics, work is a very specific term and has a more specific meaning than its everyday meaning. For example, you may think that studying for a test, or sitting at a desk and doing your homework is doing work. After all, it can be quite exhausting. However, in terms of the physical definition for work, you are not doing work because nothing is moving or changing position.

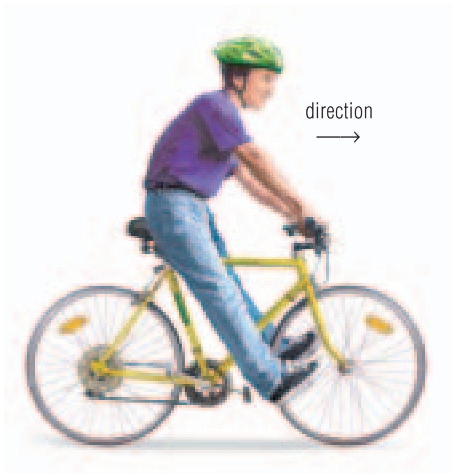


FIGURE B1.37 When coasting on a bicycle, the rider is travelling over a distance, but no force is being applied.

There are three conditions for work to be done on an object:

1. There must be movement.
   Someone pushing against a wall with 100 N of force is not doing any work on the wall because the wall does not move.

2. There must be a force.
   A person riding a bicycle that is coasting (Figure B1.37) is not doing any work on the bike because even though there is movement, the person is not applying a horizontal force to the bike.

3. The force and the distance the object travels must be in the same direction.
   A person is not doing any work on a pack (Figure B1.38) when she's carrying it parallel to the ground because the force of her hand on the pack is vertical and the distance the pack travels is horizontal.

FIGURE B1.38 Carrying a pack can be strenuous, but are you doing work?

Activity B5

Inquiry Lab

Student Reference 2, 5, 6, 7, 11

Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Doing Work

Before You Start...

The energy that is supplied to do work on an object is called "work input." When work is done on an object, it gains energy. The work equivalent of this energy is called "work output."

The Question

How much work must be done to move an object a given distance up an inclined plane?

Variables

Read over the procedure and identify the manipulated, responding, and controlled variables in the investigation.

Materials and Equipment

inclined plane

block of wood, with or without wheels, and a hook to attach the spring scale

metre-stick

spring scale (measuring in newtons of force)

string

protractor

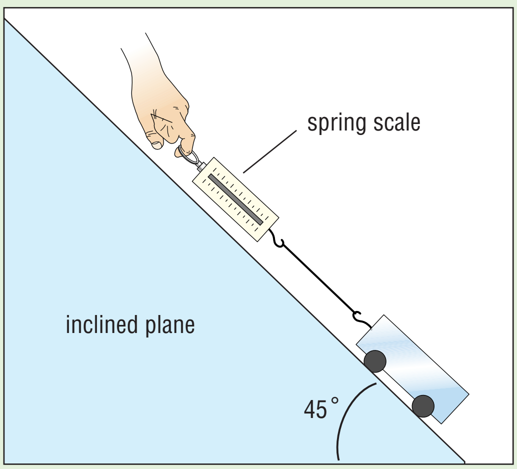


FIGURE B1.39 Step 8

Procedure

1. Set up an inclined plane, at least 60.0 cm long, at an angle of about 45°, or place one end of a long board on a stack of books and the other end on a table so that the angle of the board is about 45°.
2. At the 0.50-m mark, measure the vertical height of the inclined plane from the tabletop. Record this value in your notebook.
3. Measure the weight of the block of wood by suspending it from the spring scale. Record this value in your notebook.
4. Attach one end of a string to the hook on the block of wood and the other end to the spring scale.
5. Place the block of wood near the bottom of the inclined plane so that the spring scale is holding the block of wood at rest on the inclined plane. Use the marker to mark the position of the front end of the block on the board. This will indicate the starting position.
6. From this starting position, use a metre-stick to measure and mark the distance in 10.0-cm increments up the inclined plane. There should be at least five increments.
7. Create a data table in your notebook like the one below. Make sure your data table has a title.

Distance *d* (m)	Force *F* (N)
0.00	
0.10	

8. Using the spring scale attached to the block, slowly pull the block up the inclined plane (Figure B1.39). Be sure to pull at a steady rate so that the block maintains the same speed the entire way up the inclined plane.
9. Have your partner note the reading on the spring scale at the initial mark and at each of the 10.0-cm marks as you pull the block of wood up the inclined plane.
10. Record your readings on the scale at each increment.

Analyzing and Interpreting

1. Draw a graph of force as a function of the distance travelled by the block. Make sure that distance (the manipulated variable) is on the horizontal axis of the graph and force (the responding variable) is on the vertical axis of the graph.
2. Plot the points on the graph and then draw a line of best fit through the points.
3. At the 0.50-m point on the *x*-axis, draw a vertical line from the *x*-axis to the line of best fit. Do the same at the 0.0 point. The figure that you have created should resemble a rectangle.
4. Shade in this rectangle with a colored pencil.
5. Determine the area of the rectangle using:

   area = (length of *y*-axis)(width of *x*-axis)
6. What does the value of the area under the line represent? Look at the units of measurement of the length and width to help you answer this question.

   Hint: If $W = Fd$

   and if area = (length of *y*-axis or F) (length of *x*-axis or d)

   then what does the area represent?
7. Is the value you calculated from the area a work input or a work output?
8. Determine the work done in lifting the block of wood a vertical distance by using the height of the inclined plane at 0.50 m, the weight of the block, and the formula

   $W = Fd$ where F is the weight and d is the vertical distance.
9. Is this value a work input or work output?

Forming Conclusions

10. Are the values of work input and work output equal?
11. Which value would you suggest is the "useful" work done?
12. If the values are not the same, suggest reasons why they are not the same.

Extending

13. Conduct the experiment again after changing the height of the inclined plane. Predict how the experimental results will change.

The Relationship between Work Output and Work Input

When a force is applied to move an object through a distance, work is done on the object. This is called the work input or energy input. The work input can be calculated using the formula $W = Fd$. Suppose the force applied to the object is constant throughout the distance that it acts on the object. In that case, a force–distance graph should be a straight horizontal line. The area under the line of best fit can be used to determine the work input. The object gains energy as a result of this work done on the object. This energy is called energy output or work output.

In the absence of any outside forces, such as friction, the total work input should equal the total work output.

reSEARCH

The unit for specifying the amount of work done is given in joules. Use the Internet or the local library to research the origin of the name for this unit. Write a brief summary of your findings. Begin your search at www.pearsoned.ca/school/science10

Example Problem B1.11

A weightlifter lifts a barbell a vertical distance of 2.40 m. If the average force required to lift the barbell is 2.00×10^3 N, how much work is done by the weightlifter on the barbell?

$$W = Fd$$
$$= (2.00 \times 10^3\ \text{N})(2.40\ \text{m})$$
$$= 4.80 \times 10^3\ \text{J}$$

The work done by the weightlifter is 4.80×10^3 J or 4.80 kJ.

Practice Problems

18. A tugboat is towing a tanker through a canal using a towrope. Calculate the work done by the tugboat if it applies an average horizontal force of 6.50×10^3 N on the towrope while towing the tanker through a horizontal distance of 150 m.

19. A large crane did 2.2×10^4 J of work in lifting a demolition ball a vertical distance of 9.5 m. Calculate the average force exerted by the chain of the crane on the demolition ball.

Energy

If a body has energy, then the body can do work by transferring the energy to another object. This leads to the definition of energy. **Energy** is the ability to do work. Work and energy are actually the same thing. If a body does work on an object, then the body doing the work loses energy, and the object that has work done to it gains energy. For example, a pool cue loses energy as it hits a ball, and the ball, once hit, gains the energy the cue loses. An energy transfer has occurred.

Since work and a change in energy are the same, then they must have the same units. If work is given in joules (J), then energy is also given in joules.

$$\text{change in energy} = \text{work}$$
$$\Delta E = W$$
$$\text{J} = \text{J}$$

Example Problem B1.12

A weightlifter does 4.80×10^3 J of work in lifting a barbell. How much energy is gained by the barbell?

Since $\Delta E = W$

and $W = 4.80 \times 10^3$ J

then $\Delta E = 4.80 \times 10^3$ J

Practice Problem

20. A large crane does 2.2 x 10^4 J of work in lifting an object. How much energy is gained by the object?

B1.4 Check and Reflect

Knowledge

1. What is force? Use an example in your explanation.

2. What happens to an object when work is done on it?

3. Explain how force, energy, and work are related.

4. Force is measured in newtons, which is a derived unit. What is one newton (N) in terms of the fundamental units of measurement, which are m, kg, and s?

Applications

5. Explain why there is no work being done by the student in the following situations:
   a) studying two hours for a test
   b) carrying a book across the room
   c) dropping a ball

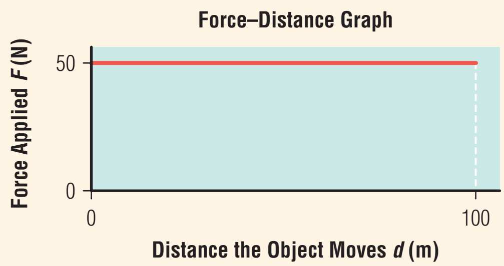
6. Calculate the work done in each of the following situations.
   a) A 98.0-N rock is lifted a vertical distance of 1.50 m.
   b) A boy applies a horizontal force of 25.0 N on a sleigh and pushes it 2.00 m horizontally.
   c) A mother cat picks up a 2.00-N kitten in her mouth and lifts it vertically 0.100 m. With the kitten in her mouth, the mother cat then carries the kitten 10.0 m across the room.

7. A worker does 43.0 J of work in moving an object 3.20 m horizontally across a floor. How much force did the worker exert in doing the work on the object?

8. A machine does 2.00×10^4 J of work in lifting an object. If the force exerted by the machine was 1.20×10^3 N, how high did the machine lift the object?

9. A person applies a force of 30.0 N in sliding an object 1.30 m up a ramp. What is the work done by the person along the ramp? Is this work a work input or a work output?

10. The graph below shows the relationship between the constant force applied as a function of the distance that the object is moved.



   a) Calculate the area under the line for the distance from 0 m to 100 m.
   b) What does the area under the line represent?

Extensions

11. Does your heart do work? Explain.

12. A weightlifter strains to lift a 1000-N barbell a vertical distance of 2.30 m from the ground to a position above his head. He then holds the barbell above his head for a time period. Is he doing more, less, or the same work holding the barbell above his head as compared to the work done in lifting the barbell to that position? Justify your answer.

13. Is the force of gravity a push or a pull? Explain your answer.

14. A spacecraft has left Earth's atmosphere and is travelling through space to the Moon. Explain why the engines in the spacecraft can be shut off at this point and the spacecraft will still reach the Moon.

UNIT B 1.0

Section Review

Knowledge

1. What is the difference between uniform motion and accelerated motion?

2. What is the difference between average speed and average velocity for an object?

3. Does a car's speedometer measure the speed or the velocity of an object?

4. What does the slope of a distance–time graph indicate?

5. Identify the following measurements as scalar or vector quantities.
a) 2.30 km
b) 40 km/h [W]
c) 50°C
d) 25 cm [S]
e) 2.0 h

6. Describe the type of motion that an object will have if:
a) balanced forces act on the object
b) an unbalanced force acts on the object

7. Why do work and energy have the same units?

8. If 15.0 J of work is done on an object, how much energy must the object gain?

Applications

9. A dog walks a total distance of 23.0 m in 14.2 s. What is the average speed of the dog?

10. A motorboat moving at an average speed of 5.30 m/s travels in a straight line for 55.0 s. What is the distance travelled by the boat?

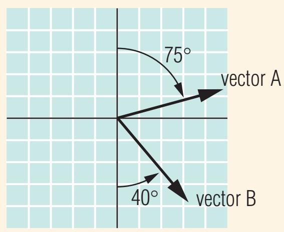
11. An airplane flying at an average speed of 800 km/h travels from City A to City B, a distance of 4200 km. How long will it take the plane to complete its journey?

12. The table at the top of the next column shows data obtained when a police radar gun measured the speed of a car at 1.00 s intervals.
a) Draw a speed–time graph with time on the horizontal axis.
b) Calculate the slope of the graph and state what this slope represents.
c) Calculate the area under the line of the graph and state what this area represents.

Time t (s)	Speed v (m/s)
0.00	20.0
1.00	20.0
2.00	20.1
3.00	19.9
4.00	20.0
5.00	20.2

13. A student walks 2.0 m [E], then 5.0 m [W].
a) What is the total distance travelled by the student?
b) What is the total displacement of the student?

14. The motion of objects A and B are represented by vector arrows shown in the diagram below. State the direction of vectors A and B using:
a) the navigator method
b) the *x*-axis method



15. A jogger runs 500 m [N] in 150 s, then turns around and runs 300 m [S] in 100 s. Determine the jogger's
a) distance travelled
b) displacement
c) average speed
d) average velocity

16. The table below shows data for an object travelling at a uniform velocity.

Time t (s)	Position $\vec{d}$ (m) [N]
0.00	0.00
2.00	6.00
4.00	12.00
6.00	18.00
8.00	24.00
10.00	30.00

Section Review

a) Draw a position–time graph of the object.
b) Calculate the slope of the graph and describe what this value represents.

17. A ball, initially at rest, rolls down an incline and speeds up to 4.50 m/s in 8.00 s. What is the magnitude of the ball's acceleration?

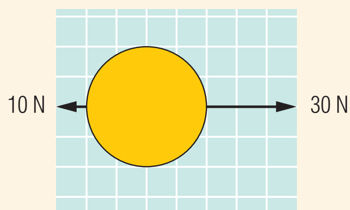
18. A car accelerates from rest at the rate of 3.00 m/s² [W] for 4.00 s. What is the velocity of the car at the end of the 4.00 s?

19. How long will it take for a girl running at a velocity of 2.50 m/s [N] to reach a velocity of 4.00 m/s [N], if she is accelerating at the rate of 0.500 m/s² [N]?

20. The velocity of an object was recorded each second for 5.00 s, as shown in the table below.
a) Plot a velocity–time graph.
b) What does the shape of the graph indicate about the object's motion?

Time t (s)	Velocity $\vec{v}$ (m/s) [E]
0.00	0.00
1.00	3.00
2.00	6.00
3.00	9.00
4.00	12.00
5.00	15.00

21. What is the unbalanced force acting on the following object?



22. A force of 15.0 N moves an object through a displacement of 40.0 m. What is the work done on the object?

23. A force of 35 N acts on an object through a vertical displacement of 3.0 m. How much energy does the object gain?

24. Moving a crate through a horizontal displacement of 10.0 m causes 350 J of work to be done. How much force must be applied to the crate to do this work?

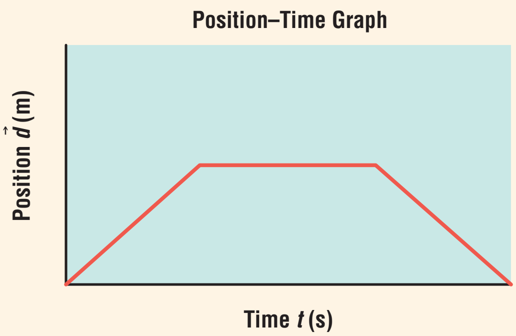
Extensions

25. a) Can the displacement of an object from its starting position ever be greater than the total distance travelled?
b) Can the total distance travelled of an object ever be greater than the displacement of the object from its starting position?

26. Is it possible for an object to have an average speed of 2.0 m/s and at the same time have an average velocity of 0 m/s? Justify your answer.

27. A car travels at a velocity of 100 km/h [E] for 3.00 h and then at a velocity of 110 km/h [E] for 1.00 h. What is the average velocity of the car?

28. The motion of a vehicle is shown in the position–time graph shown here.
a) Describe the motion of the vehicle in each of the segments shown in the graph.
b) Draw a velocity–time graph of the motion of the vehicle.



29. a) A car on a journey from Edmonton to Red Deer is travelling at a speed of 100 km/h. Does the engine of the car have to be operating to provide the necessary energy to maintain this constant speed? Explain your answer.
b) A spacecraft is travelling at a speed of 28 000 km/h on its way to Mars. Do the engines of the spacecraft have to be operating to provide the necessary energy to maintain this constant speed? Explain your answer.

UNIT B

2.0

Energy in mechanical systems can be described both numerically and graphically.

Key Concepts

In this section, you will learn about the following key concepts:

- forms and interconversions of energy
- mechanical energy conversions and work
- design and function of technological systems and devices involving potential and kinetic energy, and thermal energy conversions

Learning Outcomes

When you have completed this section, you will be able to:

- illustrate, by use of examples from natural and technological systems, that energy exists in a variety of forms
- describe, qualitatively, current and past technologies used to transform energy from one form to another, and that energy transfer technologies produce measurable changes in motion, shape, or temperature
- analyze and illustrate how the concept of energy developed from observation of heat and mechanical devices
- describe the evidence for the presence of energy (i.e., observable physical and chemical changes, and changes in motion, shape, or temperature)
- derive the SI unit of energy and work, the joule, from fundamental units
- define kinetic energy as energy due to motion, and define potential energy as energy due to relative condition or position
- quantify kinetic energy using $E_k = \frac{1}{2}mv^2$ and relate this to energy transformations
- relate gravitational potential energy to work done using $E_p = m\vec{g}h$ and $W = Fd$ and show that a change in energy is equal to work done on a system or $\Delta E = W$
- describe chemical energy as a form of potential energy
- define gravitational potential energy as the work done against gravity

FIGURE B2.1 Inuit doing a blanket toss

A visit to Canada's Far North can be especially exciting if you happen to visit an Inuit settlement that is hosting the Arctic Summer Games. The games include traditional challenges like the blanket toss shown in Figure B2.1. In this activity, a group of Inuit men and women all hold on to a large circular blanket (originally, it used to be a large animal hide). By setting up a rhythm, they can toss a person on the blanket high into the air. Today, the blanket toss is only for recreation, but it used to serve an important purpose. In the flat barren lands of the northern tundra, there are few high hills or ridges to climb to survey the landscape. By being tossed into the air, a hunter could see over the horizon and locate herds of caribou.

The blanket toss is similar to a trampoline and is a good example of an energy transformation.

In the previous section, you studied motion and learned how to use formulas and graphs to describe it. You also studied how work, force, and energy are related. In this section, you will learn about the different forms that energy can take. You will also learn how transformations from one form to another are put to use in technological systems. You will learn how to quantify the potential and kinetic energy of an object and how mechanical energy combines both kinetic energy and potential energy.

B 2.1 Forms of Energy

The idea of energy eluded early scientists because energy is a very difficult concept to define. Ask what the definition of energy is, and what comes to mind are visions of what energy can do. For example, the Sun's energy causes snow to melt in the spring. We know that a person who has just run a marathon has used up a lot of energy. We only see the evidence of energy when something is done. So it is not surprising that the development of the concept of energy went hand in hand with the development of technologies that used energy. It was only through observing the changes in these technologies that scientists started to get a clear picture of the concept of energy.

By the 1850s, scientists were convinced of the existence of a scientific concept called energy. However, energy was still difficult to describe because it involves only an abstract idea, not a material object. Experimental evidence had supported the theory that heat was just another form of energy and that it could be converted into other forms following certain principles. With these scientific breakthroughs, scientists realized that other physical phenomena in science might be explained in terms of energy, and that other forms of energy might exist.

info BIT

The word "energy" comes from the Greek word *energos*, meaning "active." It was originally used only to describe anything in motion.

Chemical Energy

From the experiments of the early alchemists, it was known that there were "hidden secrets" in chemical reactions. While they tried to make gold by mixing the four known elements (earth, air, fire, and water), the alchemists began to discover that mixing certain chemicals could produce surprising results. Thus the science of chemistry began. However, it was not until the early 1800s that French chemist Antoine Lavoisier realized that when equal amounts of different substances burned, the chemical reactions could produce different amounts of heat. With this discovery, chemists and physicists shared a common interest in heat.

When wood burns, the energy in the cellulose molecules is released, turning to heat. This is evidence that there is energy in a chemical reaction, and that this energy can be converted to heat. **Chemical energy** is the potential energy stored in the chemical bonds of compounds. The food you eat contains chemical energy that the body uses to do work in the cells.

Electrical Energy and Magnetism

Electricity, or **electrical energy**, is the work done by moving charges. The Volta Pile (Figure B2.2) is made of stacked layers of two different metals such as copper and silver, with moistened paper sandwiched between each layer. If a wire is connected from either end of the stack to an external circuit, the Volta Pile can produce a constant electric current. Invented by Italian physicist Alessandro Volta in the early 1800s, this device constituted the first battery. It provides evidence of a connection between chemical energy and electrical energy. The study of current electricity and electrical energy thus began.

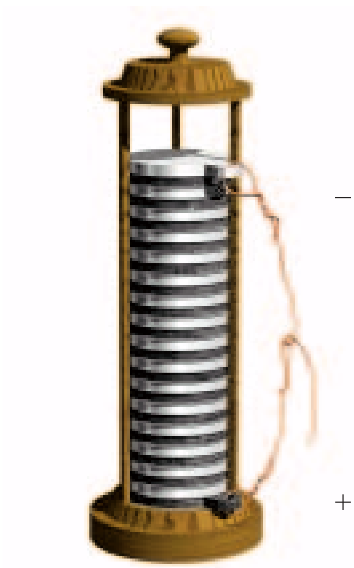


FIGURE B2.2 The Volta Pile—the first battery—was invented by Italian physicist Alessandro Volta.

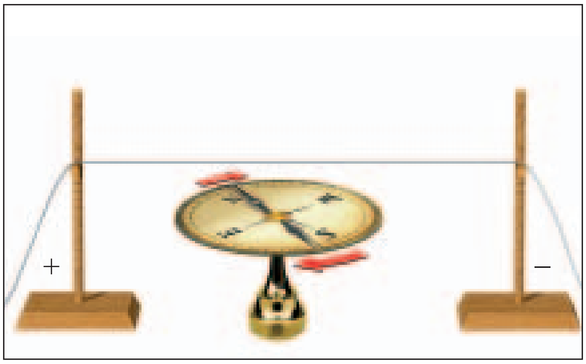


FIGURE B2.3 Oersted's experiment. As a metal wire with a current passing through it passes over the compass, the compass needle moves.

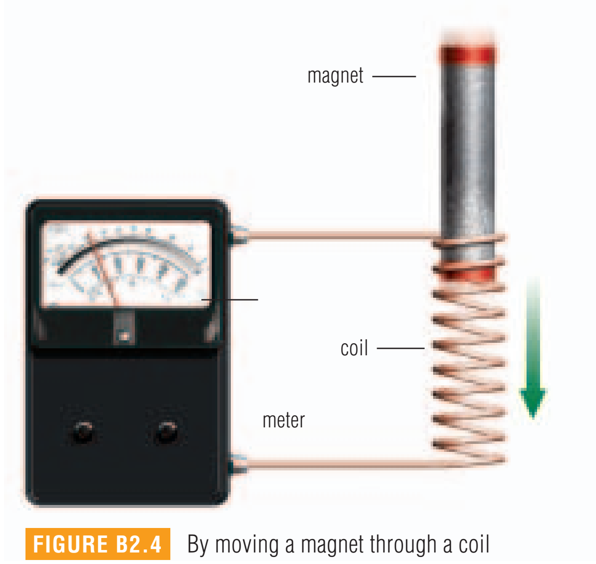


FIGURE B2.4 By moving a magnet through a coil of wire, Faraday developed the first electric generator.

If you hold a magnet above iron filings, the filings move toward the magnet, indicating that magnetism is a form of energy.

In 1820, Danish physicist and philosopher Hans Oersted discovered that an electric current in a wire could produce magnetic effects. By accident, he passed a metal wire that had a current passing through it over a compass. As he did this, he noticed that the compass needle moved (Figure B2.3). This change in the needle's position showed that electricity can produce magnetism. This discovery led to the invention of the electromagnet.

While Oersted showed that electricity can produce magnetism, Michael Faraday in London, England, in 1831 showed that the reverse can happen. He moved a magnet through a coil of wire and observed that this caused an electric current to flow through the wire (Figure B2.4).

In 1821, Estonian-German physicist Thomas Seebeck took a strip of one type of metal and joined its ends to a strip of another type of metal to form a loop (Figure B2.5). He heated one of the junctions of the two metals and kept

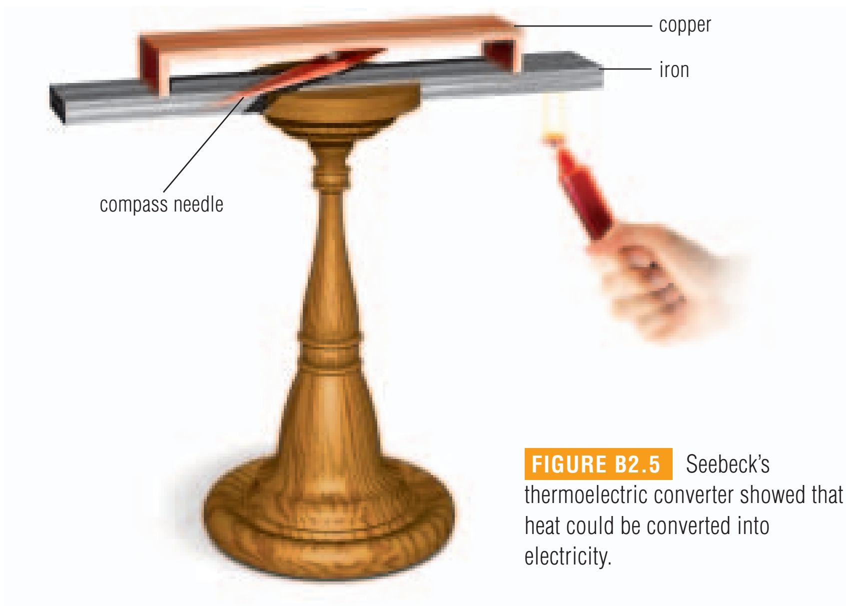


FIGURE B2.5 Seebeck's thermoelectric converter showed that heat could be converted into electricity.

the other cold. The difference in temperature between the junctions caused the electrons inside the metal to move, producing an electric current. The magnetic field created by the current caused a compass needle to move. This experiment was evidence that heat could be converted into electricity.

The invention of the light bulb by American Thomas Edison in the late 1800s showed that heat and light are two forms of energy that could be produced from electricity.

Nuclear and Solar Energy

In France, in 1896, Henri Becquerel observed that certain atoms spontaneously disintegrate, and in the process, emit radiation or radiant energy. This led to the development of a new source of energy, nuclear energy. **Nuclear energy** is the potential energy stored in the nucleus of an atom. When the nucleus of an atom is split (nuclear fission) or when the nuclei of two atoms combine (nuclear fusion), this energy is released.

Originally, scientists thought that the source of energy in the Sun was chemical energy from burning. However, they soon realized that it would take only about five thousand years before all the mass of the Sun was burned up completely. Once the secrets of nuclear fission and fusion reactions were discovered, scientists then understood that these reactions must be the source of energy in the Sun. **Solar energy** results from a hydrogen–hydrogen nuclear fusion reaction with the release of nuclear energy. This radiant energy travels to Earth as electromagnetic radiation. It is converted to other forms of energy such as heat.

Motion and Energy

When a group of English scientists watched a demonstration of a Newton's cradle (Figure B2.6) in 1666, it caused great concern. They had no idea why the ball on the opposite side rises to nearly the same height as the first ball. At that time, there were no theories to explain the ball's motion.

About 20 years after this demonstration, German philosopher and mathematician Gottfried Leibniz reasoned that whatever caused the ball to move resembled a force that seemed to be transmitted through the balls. He called this physical quantity *vis viva*, a Latin word meaning "living force." (The term "energy" wasn't used until the 1850s, but for simplicity, "energy" is used here instead of *vis viva*.) He also reasoned that two types of energy could be observed in nature.

1. Flowing water, wind, or any object in motion could be made to do work because of its motion, and thus has **kinetic energy**.
2. An object raised above Earth's surface has the potential to do work because of its position, and thus has **gravitational potential energy**.

Although Leibniz had mistaken energy for a force, his definitions of kinetic and potential energy were accurate. The sum of the energy of motion and position is known as **mechanical energy**.

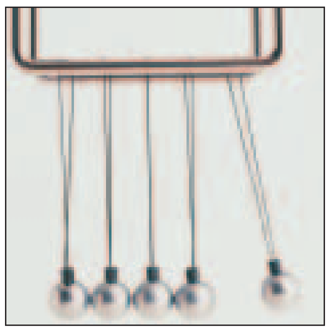


FIGURE B2.6 When a metal ball on one side is pulled away a certain distance and released, it swings back and collides with the other balls in a line. After the collision, the first ball remains nearly motionless, while a ball at the opposite end rises to almost the same height.

Activity B6

Inquiry Lab

Student Reference 2, 7

Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Mechanical Energy and Heat

The Question

What is the relationship between mechanical energy and heat?

The Hypothesis

In this activity, you will be applying mechanical energy to a system. State a hypothesis about the relationship between the amount of mechanical energy you apply and the heat gained by the system.

Variables

Read through the procedure for this experiment. Identify the manipulated, responding, and controlled variables.

Materials and Equipment

300 mL of water at room temperature

500-mL beaker

thermometer

egg beater

Procedure

1. Construct a table like the one below to record your data:

Time of Beating (min)	Temperature of Water (°C)
0	
2	
4	
6	
8	
10	

2. Pour the water into the beaker. Use the thermometer to measure the temperature of the water. Make sure that it is at room temperature (about 25°C). Record this value in the temperature column in your table at time 0 min.
3. Place the egg beater in the water and beat the water at a steady rate for 2 minutes. Quickly record the final temperature of the water.
4. Repeat procedure step 3 four more times. Make sure that you begin the next 2-minute period of beating quickly, to prevent the water from cooling off.

Analyzing and Interpreting

1. Using your data, draw a graph of temperature as a function of the time you used the egg beater.
2. What is the shape of the line of best fit of your graph? What does this shape indicate about the relationship between the time of beating and the temperature of the water?
3. Which of the variables on the graph corresponds to the mechanical energy applied to the system?
4. Which of the variables on the graph corresponds to the heat gained by the system?

Forming Conclusions

5. Based on your graph, explain the relationship between the mechanical energy applied to the system and the heat gained by the system.
6. Does the experiment prove your original hypothesis? If not, modify your hypothesis to fit the results of your experiment.

Heat and Energy

At about the same period, other scientists were puzzling over what caused heat. The ancient Greeks had no knowledge of the concept of energy, but they speculated about what the heat from fire actually was. One group of Greek philosophers, called Atomists, thought that heat was somehow related to the motion of "atoms," or tiny particles, within a substance. However, this idea seemed ridiculous to another group of Greek scientists who believed that the existence of atoms was impossible. Thus, the relation of heat to atomic motion was largely forgotten until the 1700s.

In 1750, Scottish physician Joseph Black observed that when a cold object is placed in a cup of hot water, and then removed, the object becomes much warmer. He explained this by suggesting heat was an invisible fluid, called a caloric fluid, which flows naturally from hot to cold things. Black mistakenly thought that a substance was being transferred from the water to the spoon. However, his observation on the flow of heat became one of the principles of **thermodynamics**, a science dealing with the study of the interrelationships of heat, work, and energy.

While Black was trying to perfect his caloric theory for heat, other scientists were reviving the theory that atomic motion explained heat. They suggested that the movement of atoms within a substance determines the thermal energy of the substance. Atoms move or vibrate more quickly in hot than in cold substances. The transfer of this thermal energy from a hot object to a cold object is defined as **heat**.

info **BIT**

The term "calorie," which we commonly use to describe the energy content in foods, was called "caloric" by the Calorists in the 1700s. They literally burned food and measured the amount of heat it produced.

Heat and Mechanical Energy

In 1800, American-born Benjamin Thompson, who later became Count Rumford, became the minister of war in Bavaria. While supervising workers boring brass cylinders to make cannons, he noticed that a huge amount of heat was being generated in the bored metal. In fact, he could boil a kettle of water on the cannon. He also noticed that this supply of heat was endless, so long as the workers continued boring the hole. The experiments of Count Rumford produced strong evidence that heat was not a fluid as Black had thought. According to the caloric theory, the cannons would have run out of fluid at some point, but they never did. Rumford suggested that heat could be manufactured by the motion of the workers. He was the first to realize that heat and mechanical energy were related.

Scientists then started to realize that heat and mechanical energy were different types of energy that could be converted from one to the other. Around 1807, English physicist Thomas Young linked mechanical energy to Leibniz's theory of kinetic and potential energy in moving objects. While Leibniz thought an object had *either* kinetic *or* potential energy, Young correctly suggested that mechanical energy combined *both* kinetic and potential energy. He also thought that mechanical energy was related to the work a system can do. This led to the current definition of energy, which is the capacity to do work.

info **BIT**

Traditionally, First Nations peoples used a wooden drill to start fires for cooking, warmth, or drying food. The drill consisted of a stick with a string (made of tree root or sinew) wound around it, a hand rest, and a wooden base. Pulling the string turned the stick rapidly in the wooden base. This drilling motion generated enough heat to start a fire.

*re*SEARCH

Though Benjamin Thompson spent most of his life in England and became Count Rumford in Bavaria, he was actually born in America. Use the Internet and other sources to research the life of Thompson. Write a brief summary of his achievements. Why did he not live in America? Begin your search at www.pearsoned.ca/school/science10

Joule's Experiments

Later, Sadi Carnot, a French engineer, performed experiments in an attempt to transform heat into mechanical energy. He discovered that the transformation of heat into mechanical energy could only occur when thermal energy flows from a hot object to a cool object. He also discovered that in this process some heat is always lost. From these experiments, he was able to determine the laws of heat efficiency of heat engines.

By 1840, it was widely accepted that heat was not a physical substance. Scientists now realized that heat could be exchanged for mechanical energy. This led to the birth of a new concept. In England, James Prescott Joule properly substituted the term "energy" for *vis viva*. He argued that heat is just another form of energy.

Figure B2.7 illustrates Joule's experiment that supports a connection between potential energy and heat. As the masses fall, the wheel rotates, heating up the water. If the masses are increased, there is a proportional increase in the amount of heat produced, and thus a proportional increase in the water temperature. Joule explained these findings. As the masses fall, they lose gravitational potential energy. The paddle has work done to it so it gains the energy the masses lose, in the form of kinetic energy, which is then transformed into heat.

Figure B2.8 illustrates Joule's experiment that supports a connection between kinetic energy and heat. In this experiment, a block of wood is in motion and so has kinetic energy as it falls. However, it loses kinetic energy when it collides with the other block. During the collision, the temperature of the other block increases. When the speed of the falling block is increased, its kinetic energy is also increased, and a corresponding temperature increase happens in the other block. Again, Joule explained these observations. As one block collides with the other, the first loses kinetic energy and the second one gains this energy in the form of heat.

Early scientists and engineers wanted to use energy to do useful work. They created technologies and they refined them. Scientists' concepts of energy, work, and heat were also refined, ultimately leading to the principles of thermodynamics, which you will study in section B3.0.

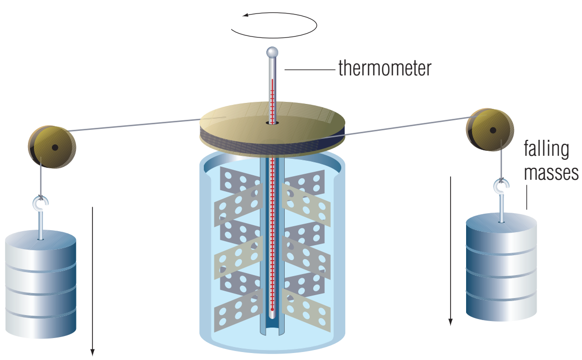


FIGURE B2.7 Joule's experiment that supported a connection between potential energy and heat

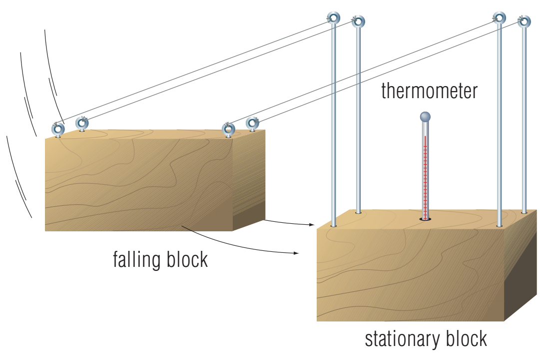


FIGURE B2.8 Joule's experiment that supported a connection between kinetic energy and heat

Career and Profile

Power Engineer

Perry Ambrose has worked for 13 years as a Power Engineer at EPCOR's Rossdale Generation Station in Edmonton. EPCOR is an Edmonton-based utility company that focusses on power generation, distribution, and transmission.

Describe your job.
Generally speaking, I am responsible for ensuring that the power plant is operating safely, reliably, and efficiently. My duties include monitoring and evaluating all equipment and systems that keep the plant running, and ensuring that we are adhering to environmental standards. I am also required to respond to "load changes," which means starting and stopping the power generators when necessary.

At the start of my 12-hour shift, I check on the equipment. I start at the top of the boiler and walk down it, looking and listening for leaks or other problems.

After that, I check the turbine-generator for problems with the oil pressure and temperature, and look for abnormal conditions. I then check the pumps, feedwater heaters, and compressors for abnormal conditions. Then, I take water samples from the boiler and check them to ensure we have the right chemicals in the boiler water. The rest of my shift is spent checking equipment, isolating equipment for maintenance work, and re-doing the troubleshooting rounds.

What education is required to do your job?
I went through the power-engineering program at the Northern Alberta Institute of Technology (NAIT). Anyone interested in this line of work should have strong math and physics skills and a mechanical aptitude.

What are the possibilities for a career in this field?
You can use these job skills in other areas besides power generation. For example, you can be a process operator in the pulp, paper, and petrochemical industries, or work in any area related to pressure vessels and inspections. The settings can also vary. You can even decide to pursue a career with the government's boilers branch. The majority of these jobs entail shift work.

What is the most interesting part of your job?
Personally, I like the troubleshooting aspect of the job. This gives me the greatest sense of accomplishment. A lot of the work is predictable, but when alarms go off, you have to be ready to identify and correct the problem right away. This could mean determining why a piece of equipment isn't working, or whether a valve is malfunctioning. In the end, if the plant's process isn't running as smoothly as it should, then it's your job to find out why.

1. What education is required to pursue a career as a power engineer?
2. What aspect of a career in power technology would you find most interesting?

B2.1 Check and Reflect

Knowledge

1. Oersted showed experimentally that electricity can produce magnetism. Who demonstrated that magnetism can produce electricity, which is the reverse?
2. For each of the following scientists, describe his invention, the type of energy the inventor was able to produce, and how it was produced.
   a) Oersted
   b) Faraday
   c) Seebeck
   d) Edison
   e) Volta
3. For each of the inventions identified in question 2, state a practical use of the invention today.
4. What is the difference between nuclear fusion and nuclear fission? How are they similar?
5. What did early scientists think was the source of energy from the Sun? Why was their theory not accepted?
6. What is the modern theory of the source of energy from the Sun?
7. Why was it difficult for ancient Greek scientists to define energy?
8. In the Newton's cradle demonstration, how did the scientists of the 1600s explain the fact that the ball at the opposite end of the row would rise to the same height?
9. Describe the contributions the following people made to the nature of heat:
   a) Sadi Carnot
   b) James Young
   c) Joseph Black
   d) Count Rumford
10. Using Figure B2.7, explain how Joule proved that heat could be produced from potential energy. In your description, state the manipulated variable and the responding variable, and describe how a change in the manipulated variable affected the responding variable.

Applications

11. In your science classroom, list all the different forms of energy you can see.
12. Given the following situations, identify the major form of energy involved.
    a) An antacid tablet is placed in a glass of water and the tablet starts to bubble.
    b) A fluorescent dial on a wristwatch glows at night.
    c) A downhill skier begins to ski down the slope with increasing speed.
    d) A tingling sensation is felt on the tongue when it is touched to the terminals of a 9-V battery.
    e) The inside of a car gets extremely warm if the car is left in the sunshine.
    f) A seagull lifts a clam high above the beach.
    g) A compass needle held over the surface of Earth points north.
13. Describe an appliance or machine that, for its operation, requires the following forms of energy:
    a) chemical
    b) light
    c) heat
    d) electrical
    e) magnetic
14. Describe an appliance or machine that produces the following forms of energy, as it operates:
    a) chemical
    b) light
    c) thermal
    d) electrical
    e) magnetic

Extension

15. How would you design an experiment to investigate whether sound is a form of energy?

B 2.2 Potential Energy

Sometimes, the force applied to an object is being used not to change the motion of the object, but to oppose another force acting on the object. In Figure B2.9, a force is applied to lift the car on the midway ride against the downward force of Earth's gravity. Application of an upward force to lift the car through a vertical distance results in work being done on the car. Recall that if work is being done, the person or object doing work must lose energy. This energy is transferred to the car, and the car gains kinetic energy. However, when the car reaches the top, it stops gaining kinetic energy because it is no longer moving. What has happened to the energy?

The car has gained potential energy. In some cases, an object may store energy because of its position relative to some other object. It is called **potential energy** because it has the potential to do work. Potential energy is energy that is stored or held in readiness. There are several types of potential energy. The type of potential energy depends on how the energy is stored.

FIGURE B2.9 As the car on the ride slowly rises, it gains energy from the work being done to lift it. Once at the top, it still has energy even though it is not moving. As the ride's car falls, it starts to lose the gravitational potential energy it gained.

Gravitational Potential Energy

In the case of the midway ride, a force is applied against the force of gravity (or the weight of the object), resulting in energy being stored. The energy stored in the car at any position above Earth is called gravitational potential energy, $E_{p(grav)}$.

Note that there is an important difference between the mass of an object and its weight. Mass (m) is a scalar quantity and is measured in kilograms (kg). The weight of the object ($\vec{W}$) is a vector quantity. It is a measure of the force of gravitational attraction on an object in newtons (N). The mass of an object does not change because the amount of matter the object possesses is constant. However, the weight of an object depends on the acceleration due to gravity ($\vec{g}$), and this value changes, so the weight of an object can change. For example, on the Moon, you would weigh less than you do on Earth because gravity is weaker on the Moon. But your mass would be the same because the size and shape of your body hasn't changed.

The equation that determines the weight of an object from its mass is:

$$\vec{W} = m\vec{g}$$

Suppose a person has a mass of 50.0 kg on the surface of Earth where the value of the acceleration due to gravity is 9.81 m/s^2. The person's weight would be:

$$\begin{aligned}\vec{W} &= m\vec{g} \\ &= (50.0\text{ kg})(9.81\text{ m/s}^2) \\ &= 491\text{ N}\end{aligned}$$

The acceleration due to gravity ($\vec{g}$) represents the strength of Earth's gravitational field. Its value near the surface is 9.81 m/s^2. You will learn more about $\vec{g}$ in future science studies.

*info*BIT

Isaac Newton was the first to realize that the natural state of all objects was to maintain uniform motion or stay at rest. He also noted that all objects tend to resist a change in this state. This tendency to resist a change in motion is called "inertia." It is a property of all matter. The more massive an object is, the harder it is to change its motion; thus the more inertia it has. This led to a definition of mass as "the amount of inertia an object possesses."

*info*BIT

The top block of limestone on the Great Pyramid in Giza, Egypt, has a mass of about 1 tonne. To lift it into position, workers had to do approximately 1 400 000 J of work against the force of gravity. This work has been stored in the limestone block as gravitational potential energy for almost 5000 years!

To calculate the gravitational potential energy, use the following formula:

gravitational potential energy = work done to lift object through a vertical height

$$E_{p(grav)} = W$$

$$E_{p(grav)} = Fd$$

$$J = N{\cdot}m$$

$$J = J$$

OR

gravitational potential energy = (mass of object)(acceleration due to gravity)(height above the ground)

$$E_{p(grav)} = mgh$$

$$J = (kg)(m/s^2)(m)$$

$$J = J$$

Note: g = acceleration due to gravity

$= 9.81\ m/s^2$

(Use the scalar value of the acceleration due to gravity in all calculations involving gravitational potential energy.)

Example Problem B2.1

A 3.00-kg box is lifted by an upward force 1.50 m above the surface of Earth to the top of a table. What is the potential energy stored in the box at this new position?

$$\begin{aligned} E_{p(grav)} &= mgh \\ &= (3.00\ kg)(9.81\ m/s^2)(1.50\ m) \\ &= 44.1\ J \end{aligned}$$

The gravitational potential energy of the box is now 44.1 J.

Practice Problem

1. A child with a mass of 25.0 kg is at the top of a slide in an amusement park. If the vertical height of the slide is 4.00 m, calculate the gravitational potential energy of the child relative to the ground.

Example Problem B2.2

A 55.0-kg diver standing on a diving platform has a gravitational potential energy of 5.40×10^3 J. What is the vertical height of the diving platform?

$$E_p = mgh$$

$$h = \frac{E_p}{mg}$$

$$= \frac{5.40 \times 10^3 \text{ J}}{(55.0 \text{ kg})(9.81 \frac{\text{m}}{\text{s}^2})}$$

$$= \frac{5.40 \times 10^3 \frac{\cancel{\text{kg}}\cdot\text{m}^2}{\cancel{\text{s}^2}}}{(55.0 \cancel{\text{kg}})(9.81 \frac{\text{m}}{\cancel{\text{s}^2}})}$$

$$= 10.0 \text{ m}$$

The vertical height of the diving board is 10.0 m.

Practice Problems

2. An 800-g bird has 47.0 J of gravitational potential energy when it is perched high up in a tree. Calculate the bird's vertical height from the ground.

3. A hanging sign is 3.00 m above the ground and has 1.47×10^3 J of gravitational potential energy. Calculate the mass of the sign.

Elastic Potential Energy

There are other situations in which a force can be applied against an opposing force, resulting in a change in potential energy. If a force is used to stretch an elastic, the force acts against the elastic force of the material. This results in a change in the shape of the elastic and in energy being stored. This energy is called **elastic potential energy**, $E_{p(elas)}$. This is also the type of energy stored in a stretched or compressed spring, a trampoline (Figure B2.10), or a spring diving board.

These are all examples of work being done by applying a force through a distance against an opposing force, which results in an energy transfer to the object. This energy is then stored in the object as potential energy.

FIGURE B2.10 The person exerts a stretching force on the trampoline.

Activity B7

Inquiry Lab

Student Reference 5, 6, 7

Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Catapults

The Question

What is the relationship between the gravitational potential energy of a ball on a catapult and the elastic potential energy of the catapult's elastic band?

The Hypothesis

State a hypothesis concerning the relationship between the gravitational potential energy of a small object propelled upward by a catapult and the elastic potential energy of the catapult's elastic band.

Variables

Read over the procedure and identify the type of data you will collect to support your hypothesis. State the manipulated, responding, and controlled variables in this investigation.

Materials and Equipment

10-N spring scale (measuring in newtons (N))
balance (measuring in grams (g))
empty paper towel tube or plastic tube
rubber elastic band about 5 mm thick
metre-stick
retort stand
small cork
string
masking tape
scissors

Procedure

1. Follow the instructions to make a catapult launcher.
   a) Cut the elastic band.
   b) Tape the elastic to the paper towel tube so that the elastic is fairly taut over one end of the tube.
   c) Tie a piece of string to the centre of the elastic and let the string hang down through the tube.
   d) Make a loop at the other end of the string. Attach a spring scale to this loop (Figure B2.11).

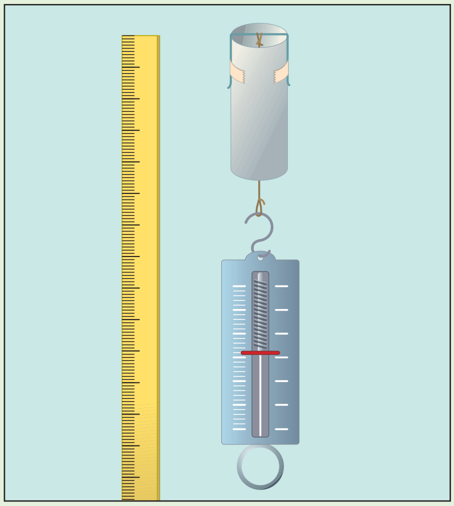


FIGURE B2.11 Step 1d)

2. Create a data table like the one below in your notebook. Make sure your data table has a title.
3. Use the balance to measure the mass of the cork in kilograms. Record this value in the appropriate column in your data table.

Trial	Force on the Spring Scale $F_{(max)}$ (N)	Initial Distance of Spring Scale d_1 (m)	Final Distance of Spring Scale d_2 (m)	Distance the Spring Scale Moves d (m)	Elastic Potential Energy of the Elastic (work done on the elastic) $E_{p(elas)} = F_{(ave)}d$ (J)	Mass of Cork m (g)	Initial Height of Cork h_1 (m)	Final Height of Cork h_2 (m)	Height the Cork Rises h (m)	Gravitational Potential Energy of Cork $E_{p(grav)} = mgh$ (J)
1										

4. Tape the metre-stick to a retort stand in a vertical position. Place the stick and the stand close to the edge of a table.

5. Hold the tube vertically with the elastic end up. Place it near the bottom of the metre-stick.

6. Note the position of the elastic on the metre-stick. Record this value as the initial distance of the spring scale in your data table.

7. Place the cork on the elastic band.

8. Slowly pull down on the spring scale and note how far you pulled it down. Record this value as the final distance of the spring scale in your data table. Remember to convert the distance to metres.

9. Note the reading on the spring scale. This is the maximum force on the elastic. Find the average force, F_{ave}, by dividing the maximum force, F_{max}, by 2. Record the average force in your data table.

CAUTION: Be careful not to aim the launcher toward any of your classmates.

10. Make sure the tube is vertical and then quickly cut the string.

11. Note the distance the cork rises vertically in the air. Record this value in the table of values.

12. Attach a new piece of string to your catapult and repeat steps 5 to 11, pulling the spring scale a different distance in each trial. Do four or five trials.

Analyzing and Interpreting

1. What was the manipulated variable in this experiment?
2. What was the responding variable in the experiment?
3. How does the elastic potential energy at the beginning of each trial correspond to the gravitational potential energy at the end of each trial?
4. Can you account for any loss in energy?

Forming Conclusions

5. Was your hypothesis correct? Support your conclusion with data from the lab.

Extending

6. Besides the amount of stretch of the elastic, can you suggest any other variables that might affect the height to which the cork rises? How could the experiment be changed to determine the effect of these variables?

Elastic and Gravitational Potential Energy and Catapults

Activity B7 demonstrates the two main types of potential energy studied in this section. If work is done on an elastic, the elastic gains elastic potential energy. When the elastic is released, the cork is propelled vertically into the air. The elastic potential energy is converted into kinetic energy of the cork. As the cork rises, the kinetic energy is converted into gravitational potential energy. If no energy is lost, then the initial work done should equal the elastic potential energy. The elastic potential energy should, in turn, equal the gravitational potential energy.

This activity shows an important point about potential energy. As you know, potential energy is energy that is stored and has the potential to do work. So, potential energy is only useful when it is converted into some other form of energy. In the activity, the elastic potential energy only becomes useful when it is converted into the kinetic energy of the moving cork. This is true of all types of potential energy. The potential energy of a battery only becomes useful when it is converted into electrical energy. The gravitational potential energy of a diver on a diving tower only becomes useful once the diver starts to dive.

*re*SEARCH

One of the factors that determines the gravitational potential energy of an object is the strength of Earth's gravitational field. The value of the acceleration due to gravity, $\vec{g}$, is 9.81 m/s^2 near the surface. However, this value changes depending on the location. Using the library or the Internet, research how the location determines the value of the acceleration due to gravity, $\vec{g}$. Write a brief summary of your findings. Begin your search at www.pearsoned.ca/school/science10

Chemical Potential Energy

The energy found in chemicals is a form of potential energy. This energy is stored in the bonds of chemical compounds. When a chemical change takes place, the positions of electric charges are altered and energy is released. Any substance that can be used to do work through a chemical reaction has potential energy. For example, the potential energy of fossil fuels such as gasoline is only released when the gasoline undergoes a chemical combustion reaction.

B2.2 Check and Reflect

Knowledge

1. Why is potential energy not as obvious as kinetic energy?
2. Identify the type of potential energy in the following situations:
   a) A rubber ball striking a wall is compressed and deformed at the exact moment it strikes the wall.
   b) An elevator in an office building slowly rises to the 20th floor and then stops.
   c) A bow string is slowly drawn back, bending a fibreglass bow.
   d) An arrow rises vertically into the air after the bow string is released.
   e) Natural gas burns in a fireplace.
3. State two differences between kinetic energy and gravitational potential energy.

Applications

4. A force of 32.0 N is required to lift a box 3.00 m vertically against the force of Earth's gravity.
   a) Calculate the work done against Earth's gravitational field.
   b) Calculate the gravitational potential energy stored in the box.
5. An object gains 155 J of gravitational potential energy when it is lifted 1.20 m above the surface of Earth. Calculate the force exerted on the object.
6. Standing on level ground, a person with a mass of 55.0 kg jumps straight up into the air to a position where the person has gained 800 J of gravitational potential energy. How high did the person leap?
7. A person jumping on a trampoline exerts an average force of 500 N in stretching the trampoline a distance of 0.750 m. Calculate the elastic potential energy stored in the trampoline.
8. An elastic that is stretched 10.0 cm has 320 J of stored elastic potential energy. Calculate the force required to stretch the elastic.
9. A 60.0-kg person climbs up a ladder to the roof of a building that is 3.50 m above the surface of Earth. Calculate the gravitational potential energy stored in the person.

Extensions

10. Suggest two ways you could increase the elastic potential energy of a spring.
11. Can an object have two values of gravitational potential energy at the same instant? Explain your answer.

B 2.3 Kinetic Energy and Motion

Motion was the first physical quantity to be associated with the concept of energy. The type of energy associated with the motion of an object is called **kinetic energy**, from the Greek word *kinema*, which means "motion." Kinetic energy can be quantified. To calculate the kinetic energy of an object, use the following formula:

$$\begin{aligned} \text{kinetic energy} &= \tfrac{1}{2}(\text{mass of the object})(\text{speed})^2 \\ E_k &= \tfrac{1}{2}mv^2 \\ \text{J} &= (\text{kg})\left(\tfrac{\text{m}}{\text{s}}\right)^2 \\ &= (\text{kg})\left(\tfrac{\text{m}}{\text{s}}\right)\left(\tfrac{\text{m}}{\text{s}}\right) \\ &= \frac{\text{kg}\cdot\text{m}^2}{\text{s}^2} \end{aligned}$$

This shows how the joule is derived from fundamental units of measurement (kilograms, metres, and seconds).

*info*BIT

A snowball, with a mass m and speed v, will have a certain amount of kinetic energy. Another snowball with twice the mass $2m$ and the same speed v, should have twice the kinetic energy. However, a third snowball with the same mass m but twice the speed $2v$, will have four times as much kinetic energy.

Example Problem B2.3

A 0.300-kg ball is pushed horizontally at a speed of 20.0 m/s. Calculate the kinetic energy of the ball at the moment it starts to move.

$$\begin{aligned} E_k &= \tfrac{1}{2}mv^2 \\ &= \tfrac{1}{2}(0.300\ \text{kg})\left(20.0\ \tfrac{\text{m}}{\text{s}}\right)^2 \\ &= 60.0\ \text{J} \end{aligned}$$

The ball has a kinetic energy of 60.0 J.

The ball in example problem B2.3 has gained kinetic energy because of an energy transfer from the work done on it. The work done came from the person applying a force on the ball to move it through a distance. The kinetic energy gained by the ball is equal to the work done.

Example Problem B2.4

The kinetic energy of an object moving at a speed of 14.2 m/s was determined to be 950 J. What is the mass of the object?

$$\begin{aligned} E_k &= \tfrac{1}{2}mv^2 \\ m &= \frac{2E_k}{v^2} \\ &= \frac{2(950\ \text{J})}{\left(14.2\ \tfrac{\text{m}}{\text{s}}\right)^2} \\ &= 9.42\ \text{kg} \end{aligned}$$

The mass of the object is 9.42 kg.

Practice Problems

4. Calculate the kinetic energy of an electron with a mass of 9.11×10^{-31} kg moving at a uniform speed of 2.00×10^5 m/s.

5. A small toy moving horizontally at a uniform speed of 2.2 m/s has a kinetic energy of 18 J. Calculate the mass of the toy.